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Abstract

Research has confirmed a lack of diversity and persistence of underrepresented populations in the STEM fields. Recruiting and retaining more women and people of color into STEM fields has long been a goal of higher education, per a notable lack of women and people of color who enter and complete undergraduate degree programs and then pursue STEM careers. Research also confirms that faculty and institutional practices promote (or not) student learning and success. Calls to improve the success of more diverse postsecondary students highlight the need for revisions to postsecondary STEM curriculum and instruction. Per their role, STEM faculty occupy a unique and potentially powerful position to influence whether or not students succeed and persevere in their fields. In this dissertation, I present three manuscripts that collectively explore issues related to STEM faculty realities and perspectives, including factors that motivate and challenge the status quo in STEM classrooms. The research in this dissertation spans two different improvement initiatives across four different postsecondary institutions. It includes the perspectives and realities of 38 postsecondary faculty and leaders in STEM and social science disciplines in examining faculty perspectives related to their teaching improvement efforts and their students' success. Findings from the three manuscripts presented in this dissertation offer novel insights concerning how faculty from multiple disciplines experience and develop a transdisciplinary curriculum, how faculty perceive notions of successful students and their teaching practices that support them, and how faculty instructional data-use practices inform their teaching practices, student learning, and reflection on their learning. I look across the three manuscripts to discuss overarching themes that emerged and provide recommendations for stakeholders (i.e., department leaders, administrators, professional development experts, and others) to support faculty involvement in improvement initiatives, particularly in STEM fields.

Faculty Perceptions and Realities Informing Curricular and Instructional Improvements in Postsecondary STEM Education: Development of Transdisciplinary Curricula, Notions of Successful Students, and the Use of Student-Learning Data

by
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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Cindy Lenhart, Author

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CONTRIBUTION OF AUTHORS

Chapter 2 - Dr. Jana Bouwma-Gearhart contributed to the design, analysis, and editing of this manuscript.

Chapter 3 - Dr. Jana Bouwma-Gearhart played an instrumental role in helping to craft and implement a plan for data analysis, to situate this work within a theoretical framework, and to edit the manuscript. Ben Ewing contributed to analysis of the data.

Chapter 4 - Dr. Jana Bouwma-Gearhart played an instrumental role in helping to craft and implement a plan for data analysis, to situate this work within a theoretical framework, and to edit the manuscript.

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CHAPTER 1 - Introduction

Rationale for Dissertation

Research highlights the need for revisions to postsecondary STEM curriculum and instruction to enhance the success of more diverse students (Austin, 2011; Henderson et al., 2011; Umbach & Wawrzynski, 2005). Per their role, STEM faculty occupy a unique and potentially powerful position to influence whether or not students succeed and persevere in their fields. Research confirms that student learning and agency are promoted by faculty and institutional practices (Ewell, 1998).

There exist a plethora of research concerning needed improvements to postsecondary STEM education. These include calls for more students to engage in more authentic scientific practices and inquiry and utilizing knowledge across disciplines towards students helping to solve timely socioscientific challenges. This call to better engage students leads to more focus on faculty teaching practices that help students learn. Faculty can create opportunities for students to attend to contemporary socioscientific problems by developing transdisciplinary curricula. Faculty can engage in more metacognitive activities that reflect on their perspectives and experiences with students and their teaching practices. And faculty can consider ways in which their instructional data-use practices might enhance their teaching and students' learning.

Understanding how postsecondary students learn and identifying "best practices" to achieve this are important considerations that have received considerable attention from researchers (Kuh, 2009b). Much of the research in this area centers around the student perspective, often situated as student identity, agency, and engagement (Kahu, 2013; Kuh, 2009b). It is equally essential to understand faculty members' perceptions and realities concerning their practices. Insights into how faculty approach teaching, how they develop curriculum, why they choose particular teaching practices, how they perceive notions of students, and how they use data to inform their teaching practices are relevant to initiatives targeting curricular and instructional improvements, particularly for faculty leaders and administrators who design professional development initiatives (Austin, 2011; Umbach & Wawrzynski, 2005). The term "teaching practices" will be used broadly to refer to educators' actions in teaching and learning environments to foster student success (e.g., creating assignments and assessment strategies, interactions with students and other educators, and employing instructional methods such as lecturing, active learning strategies, and interactive technologies).

We know that educators practice in complex professional environments. These influence their practices that, in turn, affect student success and persistence. Research reveals that organizational and departmental structures, cultural norms, and procedures may not be designed to encourage faculty to change their perceptions and may act as barriers or obstacles to reform efforts (Hora et al., 2017). Individual faculty realities and perceptions may not align with the expectations associated with departmental norms or structures. These realities may lead to a disconnect between perceived requirements and decision-making processes in teaching practices (i.e., data collection and assessment strategies, student-learning outcomes, and curriculum development). Understanding the ways faculty perceive factors that inform their teaching practices per these complexities is vital in the movement towards improving postsecondary STEM teaching practices and student learning and persistence.

In fact, these environments' social and cultural structures are created, in part, through educators' perceptions, attitudes, and actions (National Academies of Sciences, Engineering, and Medicine, 2018; Umbach & Wawrzynski, 2005). We know faculty members, like all educators, bring their perceptions, values, backgrounds, and abilities into their departments and classrooms and into their decision-making about what and how they teach (Austin, 2011). Research on faulty perceptions and realities is required to understand attitudes, knowledge, and potential unconscious beliefs that may steer faculty praxis, resulting in both affordances and barriers for diverse students. Efforts to improve teaching practices and increase student learning and persistence have proven challenging (Henderson et al., 2011). Research has revealed that some of these efforts (i.e., mandates from administrators and external forces and isolated professional development workshops) have had minimal effect on improving STEM faculty teaching practices (Henderson et al., 2011; Kezar, 2012). More research is needed on how faculty perceive and seek to improve their teaching practices to more effectively design professional development and reform activities that support faculty efforts to improve teaching practices and increase student learning and persistence (Austin, 2011; Umbach & Wawrzynski, 2005).

Research has confirmed a lack of diversity and persistence of particular student populations in the STEM fields, populations that remain "underrepresented" in STEM (National Science Foundation, 2014). Recruiting and retaining more women and people of color into STEM fields has long been a goal of many, per a notable lack of women and people of color who enter and complete undergraduate degree programs and then pursue STEM careers (Shapiro & Sax, 2011). I contend that we must better understand the perceptions and factors that can underlie and motivate both challenges and reinforcements to this status quo to inform future efforts to diversify the STEM fields. I propose that unexamined faculty perceptions are essential to uncover, especially in light of the importance of attending to the realities of marginalized groups that continue to face barriers and structures that position them in ways that disadvantage and disempower them in STEM.

Research Questions and Manuscript Overview

I present three manuscripts in this dissertation that collectively explore faculty members' perceptions and realities related to their development of curricula and instruction, their notions of students and the teaching practices that support those students, and their instructional data-use practices. I address the following research questions:

Manuscript 1:

1. What motivates across-disciplinary faculty to engage in a project to co-develop a transdisciplinary curriculum for implementation in their classes?
2. What challenges and concerns do participants experience in curriculum creation and plans for implementation?
3. What affordances support their curriculum creation and plans for implementation and any alleviation of their challenges and concerns?

Manuscript 2:

4. How do STEM faculty conceptualize successful students in their disciplines?
5. What instructional strategies do STEM faculty claim to use that they think are effective in cultivating student success in their courses?

Manuscript 3:

6. What are the instructional data-use practices of a sample of STEM faculty from one U.S. research university? How do they think these inform their teaching?
7. What affordances and constraints, including instructional technologies, do these faculty claim regarding their instructional data-use practices?
8. To what extent do faculty engage students in reflecting on their learning data?

Manuscript 1- Engaging Students Around Complex Socio-Scientific Issues: Affordances and Tensions of Faculty Working Across Disciplines To Develop Transdisciplinary Curriculum

In this first manuscript (submitted for publication to Life Science Education), I used data from a project involving STEM faculty improvement of teaching practices by exploring how across-disciplinary faculty develop a transdisciplinary curriculum module around a complex sustainability topic through a collaborative process. This study was situated in a more extensive evaluation project led by Dr. Jana Bouwma-Gearhart. As part of the evaluation team, I collected multiple data through interviews, a survey, observations, and documents/artifacts. I explored the motivations that led faculty to participate in the initiative, including their desire to improve their teaching and develop a curriculum that would benefit their students. I also explored the challenges and concerns they anticipated as part of their engagement with the project, individual and departmental, and institutional challenges and concerns. I also wanted to understand the affordances that alleviated some of the challenges and concerns.

This research is significant due to the growing recognition of the importance of engaging postsecondary students in experiences that can heighten their ability to solve complex socioscientific problems. Knowledge, methodologies, and understandings conceived and situated within typical disciplines are likely insufficient at developing citizens to help address societal problems (Gibbs, 2017; Lyall & Fletcher, 2013). Many scholars and researchers are beginning to argue for transdisciplinary experiences (i.e., transforming knowledge and skills from diverse disciplines into a common understanding) that integrate and synthesize ways of thinking across disciplines. Postsecondary faculty are encouraged to provide experiences and learning opportunities that frame problems as multidimensional and interconnected around disciplinary knowledge and skills (Barth et al., 2007). This work is not an easy lift given that higher education institutions are organized around structures and norms that have developed over centuries and do not support or, in some cases, encourage faculty to work across disciplines (Grossman et al., 2000). There is reason to anticipate such work challenging for faculty, including limited previous research around faculty working across disciplinary boundaries (Lindvig & Ulriksen, 2019). In fact, research around interdisciplinary faculty development of transdisciplinary curricula, specifically, is virtually non-existent.

This qualitative study seeks to fill the gap in understanding faculty experiences in developing transdisciplinary curricula by investigating faculty experiences from diverse disciplines, primarily sciences, business, and other social sciences across three institutions, as they collaborated to develop a transdisciplinary curriculum module to teach across their courses. I use cultural-historical activity theory (Engeström, 2001) as an analytical framework to call attention to the complexity of the social activity, as that done by faculty, situated within multi-faceted contexts, disciplines, and higher education organizations (e.g., programs, departments, institutions). I found that faculty were motivated by the potential for meeting their professional development needs, including a desire to create a curriculum around sustainability issues. Also, faculty perceived the initiative would provide them with professional development that could improve their teaching practices and develop a curriculum that would enhance student learning and content knowledge. I found faculty experienced tensions related to navigating the norms, practices, and language of faculty from different disciplines, the suitability and incorporation of a transdisciplinary curriculum into their current courses, perceptions of increased time and workload issues, and their felt confidence level with teaching and collaborating with other faculty. Faculty also perceived challenges associated with faculty and organizational attitudes, norms, and practices. I found that faculty perceived project leaders as effective facilitators and co-developers of the curriculum. Finally, I found that participation in the project alleviated concerns related to the curriculum's creation and value and increased confidence in teaching and working across disciplines.

Manuscript 2 - Uncovering the Complexity of STEM Faculty Perceptions About Successful Students and Their Teaching Strategies that Support Them

In this manuscript, I take a critical perspective on faculty perceptions of the characteristics of successful students in their classes and the teaching practices they employ to support those students. In doing so, I advance research-based recommendations towards increasing the success and persistence of students from groups historically underrepresented in postsecondary STEM, specifically related to the perceptions of faculty supporting those students. I highlight faculty perceptions that vary widely but generally focus on successful students as behaviorally, cognitively, and affectively engaged. I also highlight a range of instructional strategies that indicate faculty's motivation to support students being successful. However, I am concerned that faculty may assume that students know how to engage effectively. Students, particularly those from underrepresented groups, may not know or be positioned or empowered to take advantage of the resources and support necessary to ensure success.

Multiple factors are known to influence student success in higher education (Kuh, 2003). Regular implementation of evidence-based instructional practices (EBIPs) such as active learning strategies, problem-based activities, and group work, has shown to be critical to the success and persistence of students in STEM disciplines (Austin, 2011; Freeman et al., 2014). Research has found that EBIPs afford additional benefits for STEM students from disadvantaged and underserved backgrounds and female students in male-dominated fields (Haak et al., 2011; Lorenzo et al., 2006). Adoption of EBIPs has been slow, and reasons are numerous but include organizational cultural norms, structures, and practices (Hora et al., 2017;

Kezar, 2012). One avenue of research links EBIPs with student engagement, itself an indicator and predictor of student success in higher education (Kuh, 2009b; Tinto, 2010). The ability to foster and support diverse student success via their engagement roots many interventions targeting faculty members' pedagogical improvements (Kahu & Nelson, 2018; Kuh, 2009a). Such focus may help alleviate the impact of a plethora of barriers that stand in the way of students' success from underserved and underrepresented groups in the STEM disciplines (Pierszalowski, 2019; Pierszalowski et al., 2018).

Yet, research also shows that STEM faculty have not implemented EBIPs improvements to the degree that many have hoped for (Henderson et al., 2011). STEM faculty members' understanding, adoption, and adaptations of EBIPs is still limited and challenging (J. Bouwma-Gearhart et al., 2018; Dancy et al., 2016; Fisher et al., 2019; Henderson et al., 2011). Additional barriers to implementing evidence-based instructional practices, like active learning, are faculty perceptions (i.e., conclusions, judgments, insights, beliefs) about teaching and learning, including their teaching practices and their students' realities.

This manuscript adds to the limited research that explores STEM faculty perceptions of their notions of successful students and the relationship between those perceptions and their teaching practices. Through qualitative analysis of 19 STEM faculty at one large research university, I examine STEM faculty perceptions related to their notions of characteristics of successful students (i.e., students who are successful in their academic achievements) and the teaching practices they state they employ to support students being successful. Drawing on a conceptual framework of educators' perceptions, teaching practices, and student engagement, this study examines faculty notions of successful students and their teaching practices that they state support student success. This framework also allowed me to uncover potentially unknown and unintended perceptions, practices, and structures that may implicate larger social structures that result in inequities experienced by many individuals in STEM education. I found faculty perceive a range of characteristics and factors indicative and predictive of student success. Faculty also described a wide range of instructional strategies they perceived as effective. I offer insights into STEM faculty practices and expectations that assume and encourage groups traditionally successful in STEM while also highlighting implicit and hidden expectations of faculty that may position women, racial/ethnic, and other underrepresented groups as unsuccessful in STEM. Towards more equitable and inclusive postsecondary STEM education, I put forth recommendations to help faculty, professional developers, and other education leaders recognize and address beliefs and perceptions regarding successful students as potentially overlooked barriers that faculty may inadvertently be contributing to.

Manuscript 3 - STEM Faculty Instructional Data-Use Practices: Informing Teaching Practice and Students' Reflection On Students' Learning

After exploring faculty perspectives towards their students, I wanted to focus on a different aspect of the same faculty group toward their instructional data-use practices and how they use student learning data to inform and improve their teaching practices and engage students reflecting on their learning. In this manuscript, I highlight the affordances and constraints that faculty perceive in their instructional data-use practices. I found that faculty use various formative and summative instructional data to inform them about student learning and their instructional practices. Faculty also used instructional technology to collect student learning data, allowing them to modify their instructional practices more often and respond in timely ways to student learning. However, I am concerned that most faculty members do not intentionally engage students in reflective learning strategies that evidence suggests are effective practices to ensure student success.

In response to calls for increased accountability from policymakers, accreditation agencies, and other stakeholders, higher education institutions are devoting more resources to gathering and analyzing evidence around student learning outcomes to inform strategy promoting student success and persistence (J. Bouwma-Gearhart & Collins, 2015; Ewell & Kuh, 2010; Jenkins & Kerrigan, 2008). Specifically, educators are asked to gather and respond to evidence of student learning to inform their future teaching-related decisions and practices. The push for faculty to engage in systematic instructional data-use practices goes beyond their summative examination of students, often infrequent and not particularly illuminative (J. Bouwma-Gearhart & Collins, 2015; Hora et al., 2017), to include more formative data-use practices, including that can inform immediate teaching practices. These connote increased repertoires of practice for many faculty, placing on them additional demands and, by association, those who seek to help develop their teaching-related practices. Emerging research indicates that STEM faculty are not necessarily ready to utilize diverse instructional data effectively or to constructively inform practice generally (Hora et al., 2017). This research also suggests that faculty adoption and use of instructional technologies that may facilitate data-use practices are also slow and inconsistent (Hora & Holden, 2013). Furthermore, calls for faculty to more fully involve students in reflecting on their learning data are growing and suggest a shift in how faculty think about their use of instructional data.

This manuscript adds to the limited data on faculty perceptions of their instructional data-use practices and their engagement of students in reflecting on their learning. Through this exploratory study, I seek to examine how 19 STEM faculty gather, analyze, and use instructional data to inform teaching practices and student learning outcomes, as well as the perceptions and factors that influence faculty members' instructional data-use practices. Using affordance theory (Gibson, 1977; Norman, 1999) as a framework, I seek to illuminate the realities of educators operating in complex socio-cultural systems in light of their professional realities, including their pedagogical knowledge, skills, norms, and felt competencies. Novel findings include faculty descriptions of instructional technologies that they claimed allowed more timely and complete data to respond to more immediately in practice. Faculty who used adaptive learning technologies specifically claimed it helped them collect more nuanced data on achievement trends for different groups of students. Although all faculty used summative data (i.e., exams, written assignments), several faculty described less reliance on these typical data indicators of student learning, using other practices such as group work to measure student learning. Faculty were mixed in their practice of engaging students in reflecting on their learning data. These practices were generally described as activities in which students were asked to reflect on their overall performance in class and how their use of study techniques may (or not) be helping them. I discuss the affordances and constraints that faculty perceive in their instructional data-use practices. I also discuss implications for departmental and institutional leaders, faculty leaders, professional developers, and for faculty themselves.

Finally, I look across the three manuscripts to discuss emerging themes and insights and recommend implications and strategies for addressing STEM faculty improvement efforts that begin to tackle the complexities of teaching and learning in higher education environments.

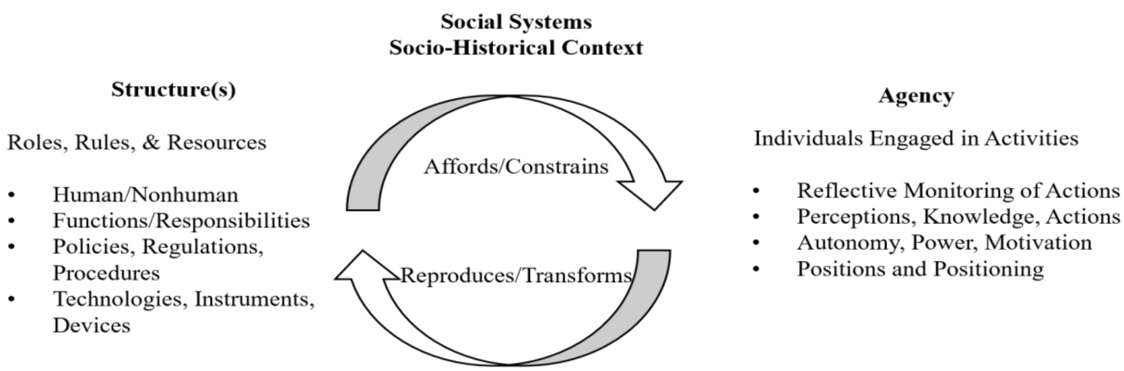
Ontology and Epistemology

I utilize a constructivist paradigmatic view in my qualitative research that examines how people construct and reconstruct meanings through daily interactions (Creswell, 2014; Leavy, 2017). The goal of this paradigm is to rely as much as possible on participants' views of the situation being studied. Questions are broad and general to understand how participants construct meaning in socially, historically situated circumstances. I recognize my background as a past faculty member and administrator in postsecondary institutions, and my position as an executive overseeing reform efforts in postsecondary institutions across the nation may shape my interpretation of perspectives, activities, and interactions. While these might be strengths that I bring to my interpretations of the complexities of postsecondary faculty interactions, my biases can also pose challenges as I examine what I think is "familiar territory" concerning faculty teaching practices. Epistemological constructivism holds that our social world is inevitably our construction rather than a purely objective perception of reality (Maxwell, 2013). To counter biases that I may hold from my previous experiences, I have employed numerous validity checks to ensure that my research is trustworthy and authentic. As Maxwell (2013) asserts, validity gets at the heart of why we should believe what a researcher is asserting; however, in qualitative research, validity does not imply the existence of "objective truth." When available, I utilized different data sources to build a coherent justification for themes (Creswell, 2014). While I privileged participant interviews, the study in manuscript one used several other data sources to situate and help confirm these findings: a survey, observations, and artifacts/ documents. As well, I engaged in a modified "member checking" strategy. I shared findings from faculty and administrator interviews with project leaders to facilitate their work and make course corrections as needed. Finally, I worked closely with Dr. Jana Bouwma-Gearhart in all the chapters to interpret findings and to draw logical conclusions. In the studies in manuscripts two and three, I ensure the trustworthiness of the analysis through peer debriefing (Creswell, 2014). Dr. Jana Bouwma-Gearhart supported the codes' development and participated in debriefing and data analysis sessions throughout the coding and analysis phases. In both manuscripts, we discussed emerging concepts and themes based on a critical reflection of the data and ongoing discussions addressed (dis)agreements with the data.

Theoretical Frameworks

My theoretical and conceptual frameworks are grounded in assumptions related to how organizational (e.g., departmental and institutional) structures and individuals' agency interact. Gidden's (1984) structuration theory provides a basis for the socio-historical context of social systems in educational environments (see Figure 1). Gidden (1984) posits social systems are comprised of *agents*, individuals (e.g., faculty and students) engaged in activities (exhibiting agency), and *structures*, including the physical and psychological (human and nonhuman) components influencing and influenced by agents. Individuals' agency depends on their perceptions and knowledge, including their autonomy, power, intentions, and motivations to reproduce, transform, or resist in social systems and environments. As such, agency implies positions and positioning within social systems (Gutiérrez & Barton, 2015).

Figure 1
Structure(s) and Agency in Complex Social Systems



Note. Interpretation of Structuration Theory (Gidden, 1984)

Structures are the social, historical entities and physical surroundings that "shape and are shaped by social practices" in environments (Varelas et al., 2015). Structure encompasses the roles, rules, and tools/resources that constitute the social, cultural, political, and historical systems in which we live (Shilling, 1992), specifically (a) roles that explain the positions, functions, and responsibilities of individuals and groups; (b) rules that entail the policies, regulations, guidelines, and procedures that govern, manage, and administer our social systems; and (c) tools that represent the resources, technologies, instruments, and devices that support the performance of work in educational environments. This broad theoretical framework provides a lens for my dissertation, while each of the manuscripts uses an analytical framework that situates the findings with the specific context of the data.

In the study detailed in my first manuscript, I use *cultural-historical activity theory* to show how interdisciplinary faculty develop transdisciplinary curriculum, highlighting various factors impacting their action. Specifically, we rely on second-generation cultural-historical activity theory (Engestrom, 2009), which recognizes six elements (or nodes) interacting in a social system. In this conception, activity systems include subjects that represent individuals or groups engaged in interactions within the system. Subjects rely on *mediating artifacts* or *tools* to guide actions to achieve an *objective* and *outcome*. Subjects work within a *community of others* regulated by rules (i.e., norms and conventions) and a *division of labor* that delineates the various actions of the subject.

In the study detailed in my second manuscript, I use an analytical framework of an "educational interface" to explore faculty notions of successful students and teaching strategies that support those students, consisting of educator perceptions, teaching practices, and student engagement as they interact in complex social systems (Kahu & Nelson, 2018). Students and educators experience and interact with factors that influence their engagement and success in the educational interface, including a belief in their capacity to perform a given task, their appraisal of their situation as affording or constraining their engagement, and their positive interpersonal interactions with others or the institution.

In the study detailed in my third manuscript, I use *perceived affordance theory* and *systems-of-practice theory* to explore how STEM faculty use student learning data to inform their teaching practices and student learning. Systems-of-practice theory conceptualizes educational environments as "a complex network of structures, tasks, and traditions that create and facilitate practice in organizations" (Halverson, 2003). Perceived affordance theory (Gibson, 1977; Norman, 1999) provides a conceptual framework for understanding how individuals' noticing and taking up environmental factors allow their actions/agency within particular social contexts, per factors relevant around a task (Bouwma-Gearhart et al., 2018; Norman, 1999).

Significance of the Dissertation

The three manuscripts in this dissertation are designed to complement one another. Ultimately, together, they represent original research around faculty perceptions of their curricular and instructional practices. Change in higher education and particularly within STEM classrooms, does not occur easily (Austin, 2011; Henderson et al., 2011). Efforts to effect significant change in STEM education must involve interventions that examine STEM faculty perceptions, attitudes, and realities (Henderson et al., 2011). My research has wide-ranging significance and implications for those promoting changes, improvements, and related interventions targeting STEM faculty practice. The topics in each of the three manuscripts of this dissertation (i.e., transdisciplinary curriculum development, notions of successful students, and instructional data-use practices) are important to understand as a base to creating opportunities to support faculty professional development towards improved student outcomes in postsecondary STEM.

I see the potential for disseminating my dissertation work to a broader audience of stakeholders. Indeed, I have already been engaged in different national conferences presenting the findings from my research, including AERA (American Educational Research Associate), NARST (National Association for Research in Science Teaching), and ASHE (The Association for the Study in Higher Education). I hope that insights from these studies will be used to inform professional development activities, departments, and leaders that seek to change and support faculty beliefs, attitudes, and knowledge related to improving teaching practices.

Research on calls for STEM faculty to improve their instructional practices has traditionally focused on systemic and institutional factors that inhibit improvements (Austin, 2011) or faculty's reluctance to implement evidence-based instructional practices (Brownell & Tanner, 2012; Patrick et al., 2016). Limited research has explored faculty's perception of their instructional and curriculum activities, teaching practices, and their students. Through the manuscripts outlined in this dissertation, I aim to bring attention to STEM faculty perspectives representing a pressing and largely unspoken issue that has implications for student success in higher education. Reifying instructional practices and the departmental and institutional structures that support them is inconsistent with our national narrative to promote inclusive excellence. I look forward to building on this work by offering insights and solutions to key stakeholders in higher education institutions, challenging structures and practices that do not examine faculty perspectives and realities, and elevating consciousness regarding opportunities for faculty to improve their teaching practices.

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CHAPTER 2 – Manuscript One

Engaging Students Around Complex Socioscientific Issues: Affordances and Tensions of Faculty Working Across Disciplines to Develop Transdisciplinary Curriculum

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Abstract

There is growing recognition of the importance of engaging postsecondary students in experiences that can heighten their ability to solve complex socio-scientific problems. *Transdisciplinary experiences* are required to integrate and synthesize knowledge, skills, and ways of thinking across typical disciplinary boundaries reflected in higher education institutions. Creating transdisciplinary student experiences, given faculty's dominant rooting within a discipline and the academy's structures and practice-norms, is challenging. Across-discipline collaborations are novel. We lack insight into successful examples and the affordances and constraints that faculty encounter working with others on transdisciplinary experiences for students. We detail a phenomenological study that describes sciences, business, and social science faculty experiences across three institutions to develop a transdisciplinary curriculum. Faculty were motivated by their professional development needs, improved teaching practices, and developed curricula that would enhance student learning. Faculty experienced tensions related to navigating norms, practices, and language, the suitability of transdisciplinary curricula, and confidence in teaching and collaborating across disciplines. Project leaders were effective facilitators and co-developers, essential to curricular development's success. We discuss implications for faculty, academic leaders, administrators, and other stakeholders interested in future efforts that involve faculty working across disciplines to develop transdisciplinary curricula to meet societal needs.

Introduction

The Hard Work of Preparing Students to Tackle Complex Socioscientific Issues

> *Developing and teaching [this] curriculum means that we're not teaching outside disciplines; we're really doing transdisciplinary and transdisciplinary means I have to see your discipline through the lens of my problem in [my] discipline.*

A leader made the above quote about a project that brought faculty from multiple disciplines together to develop innovative undergraduate programming around *problems* of sustainability, arguably one of the most critical contemporary issues for society. Alongside other *wicked problems,* such as poverty, health, social inequalities, climate change, and the COVID-19 pandemic, sustainability issues are challenging to solve because of their complexity (Rittel & Webber, 1973) in this case, implicating both natural and social phenomena and their intersection. Wicked problems require *transdisciplinary approaches,* defined as integration and synthesis of knowledge, skills, and thinking that transcends the typical boundaries of disciplines often reflected at higher education institutions (e.g., departments, academic programs) (Klein, 2013). Thus, they require problem solvers able to perform this work and, ultimately, new ways of educating students (Ertas et al., 2015; Moore et al., 2018; United Nation SDGs, 2020). Knowledge, methodologies, and understandings conceived and situated within a discipline are likely insufficient at developing citizens (e.g., undergraduate students) to help address the wicked problems society faces (Gibbs, 2017; Lyall & Fletcher, 2013). Motivated by desires for a scientifically and technologically literate citizenry ready to better tackle rapidly evolving challenges facing society globally (Brandt et al., 2013; Ertas et al., 2015; Gibbs, 2017; Moore et al., 2018), postsecondary faculty members (hereafter just *faculty*) are encouraged to provide experiences and learning opportunities that frame problems as multidimensional and interconnected around disciplinary knowledge and skills (Barth et al., 2007).

Realizing such is not an easy lift. Higher education institutions, organized around structures and norms that have developed over centuries, may stifle this work, including programs and departments organized around ways of knowing (and related curricula) that reflect fairly siloed disciplines (Grossman et al., 2000). *Disciplines* signify “the tools, methods, procedures, examples, concepts, and theories that account coherently for a set of objects or subjects" (Klein, 1990, p. 104), reflecting epistemological and social boundaries (Klaassen, 2018). Disciplines reflect specialization of knowledge, thus making problem-solving efficacious in many instances but less so in others (Aldrich, 2014). Disciplinary boundaries at institutions of higher education, reflected as departments of faculty members delivering academic programming and research, are often the basis of decisions concerning hiring, promotion and tenure practices, resource allocation, and teaching assignments, programming, and curricular development (Lattuca, 2001). Students are expected to learn or, at least, perceive via engagement with the curricula and instruction that faculty have planned for them (Lattuca & Stark, 2009), reflecting faculty values around what knowledge and skills should be studied. We have argued previously for the consideration of faculty discipline when exploring the realities of faculty grouped under the disciplines of the life sciences and STEM, including in the design and delivery of professional development for faculty around teaching improvements (Bouwma-Gearhart, Ivanovitch, et al., 2018).

Disciplines are not static. In fact, disciplines and how they are reflected in higher education evolve due to social, political, and economic factors (Lattuca, 2001). Evidence suggests that while still organized around disciplines (e.g., in departments and programs), faculty utilize greater diversity of frameworks and methods in teaching and research over time (Lattuca, 2001). Overall, as argued by Barry and Born (2013), what we know as *disciplines* are composed of many different ontological and epistemological frameworks and methodologies. Yet, faculty still struggle to engage students in experiences that span disciplines (Gibbs, 2017), per structures and norms that have historically defined their work, including norms of curricula and program development (Russell et al., 2008).

The Roles and Norms of (Discipline-based) Faculty Curricular Development and Course Planning

At the vast majority of higher education institutions, curricular development and adoption largely remain the faculty's purview (Lattuca & Stark, 2009). Lattuca and Stark (2009) suggest these processes include faculty considerations of goals for student learning (skills, knowledge, and attitudes); content (important subject matter, often discipline-based); sequence (the order in which concepts are presented); students’ characteristics (potentially impacting learning); instructional processes (how student learning may be achieved); instructional resources (teaching materials and settings available); evaluation (how to assess learning); and potential adjustments to standing or previously utilized curricula, based on past experiences. Indeed, curricula and course planning are complex activities that involve faculty members’ scholarly preparation, teaching experiences, beliefs, artifacts, and practices (Bouwma-Gearhart, Ivanovitch, et al., 2018; Bouwma-Gearhart, Lenz, et al., 2018; Hora & Ferrare, 2014; Lattuca & Stark, 2009).

Yet relatively little is known about what faculty base these considerations on, including faculty in the STEM disciplines (Bouwma-Gearhart, Ivanovitch, et al., 2018; Bouwma-Gearhart, Lenz, et al., 2018; Hora & Ferrare, 2014). We know that faculty typically receive little training and professional development regarding teaching and, by association curricular development, during typical training as graduate students (Bouwma-Gearhart, 2008; Bouwma-Gearhart et al., 2007; Bouwma-Gearhart, Lenz, et al., 2018). Faculty may significantly mimic and borrow from what they experienced as courses created by others. In a study of 58 math and science faculty, Hora & Ferrare (2013) found that STEM faculty generally considered content first when developing their courses and were guided primarily by the course syllabus and course textbook. They found that faculty generally rely on past teaching and other curricular materials in their course planning, including what they may have inherited from faculty who taught the course previously. These faculty also considered their use of certain technologies and associated teaching methods when developing curricula. Bouwma-Gearhart, Ivanovitch et al. (2018) found that postsecondary biology instructors planned specifically for their instruction by relying on their past teaching experiences; faculty who had experience teaching disciplinary material would often recycle instructional artifacts (including syllabi and class notes) when planning new courses. STEM faculty sometimes plan to implement pedagogical strategies that are meant to enhance students’ cognitive engagement, higher-order thinking skills, and scientific citizenry (Bouwma-Gearhart, Lenz, et al., 2018), also via engagement with curricula meant to be relevant to students' other life and "real world" experiences (Bouwma-Gearhart, Lenz, et al., 2018; Hora & Ferrare, 2013).

Hora and Ferrare (2013) also noted that faculty considerations varied across disciplines and were reinforced by specific disciplinary cultures. In studies of 16 postsecondary biology instructors, Bouwma-Gearhart, Ivanovitch et al. (2018) found that faculty members' plans for teaching rested upon their intended pedagogical outcomes, which included the nature of the discipline (content, concepts, skills, and processes) and the needs of their students, alongside pedagogical resources at their disposal. In a related article, Bouwma-Gearhart, Lenz et al. (2018) further detailed faculty concerns for delivering large quantities of disciplinary content as they planned curricula and instruction to meet students' needs, including attending to students' prior learning experiences and preparedness. These faculty largely described disciplinary content dictating their pedagogical strategies (e.g., if one should lecture, use a visualization), as opposed to privileging certain pedagogical practices per consideration of their efficacy. Bouwma-Gearhart, Ivanovitch et al. (2018) argued that disciplinary context cannot be relegated to "a backdrop of practice;" instead we must acknowledge "the nature and norms of a discipline as integral factors shaping educators' behavior...discipline-situated knowledge, influenced by the disciplinary culture(s) (values, beliefs, and codes of conduct norms) in which an educator has been socialized, and is drawn upon during decision-making about teaching" (p. 2).

Bouwma-Gearhart, Lenz et al. (2018) have argued that the success of the postsecondary education-related improvement efforts largely rest in attending to their teaching and learning-related conceptions rooted in their discipline-based frameworks, including their pedagogical concerns and felt competencies in meeting these. This study is one of the relatively limited studies exploring the relationship between teaching-improvement initiatives and faculty curricula-related practices. Many of these studies have concerned faculty in the STEM disciplines, given the plethora of initiatives targeting their teaching (Bouwma-Gearhart et al., 2016; Henderson et al., 2011). 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, 2008, 2012b; Bouwma-Gearhart, Lenz, et al., 2018; Bouwma-Gearhart, Ivanovitch, et al., 2018). Once engaged in faculty learning communities, these initiatives afford faculty support to overcome barriers in the way of changes to their pedagogical practices and, specifically, to make incremental revisions to curricula (Bouwma-Gearhart, Lenz, et al., 2018).

Lattuca and Stark (2009) have noted that colleagueship appears to be important in curricula/course planning even when faculty teach alone, as faculty can find working with others on curricula/course planning to inspire new ideas. Bouwma-Gearhart (2012b) found evidence of faculty members finding interdisciplinary STEM collaborations meaningful in making sense of new pedagogical practices. Bouwma-

Gearhart, Lenz et al. (2018) found that biology faculty, specifically, with less experience with disciplinary material, were more likely to seek guidance and resources from other faculty.

What We Know About Faculty Developing Curricula that Span Multiple Disciplines

While the above findings are hopeful, curricular development and course planning spanning multiple disciplinary fields may entail tricky navigation of disciplinary beliefs, knowledge, norms, and related organizational norms and practices. Curricula that span multiple disciplines are sometimes hard to decipher per conflation of *multidisciplinary*, *interdisciplinary*, and *transdisciplinary* terms, making interpreting relevant literature challenging (Jahn et al., 2012; Lindvig & Ulriksen, 2019). We draw from higher education scholars to delineate them here and how they bring together and utilize disciplinary knowledge, processes, and experts. *Multidisciplinary* approaches are generally understood to involve disciplinary experts working separately on problems, exchanging but not integrating knowledge, and students are expected to integrate disciplinary content (Fam et al., 2018; Lattuca, 2001). *Interdisciplinary* approaches involve experts working on problems that cannot be divided and are therefore investigated and informed from different disciplinary perspectives, with students expected to integrate the various disciplines (Fam et al., 2018; McClam & Flores-Scott, 2012). *Transdisciplinary* approaches transcend discipline specialization to address problems via teams or individuals from different disciplines integrating divergent disciplinary knowledge into a hybrid means for understanding and inquiry (Jahn et al., 2012; Klein, 2013). Transdisciplinary allows experts and students to attend to the complexity of socioscientific problems.

Research on the nature of faculty interdisciplinary collaborations concerning teaching and learning

Research around faculty creation of these different types of curricula requiring faculty to work across disciplines is limited. Research on the nature of faculty collaborating to develop transdisciplinary curricular development and teaching is almost nonexistent. What we know about faculty across-discipline collaborations, in general, can provide clues for understanding what might influence collaborations around transdisciplinary curricula, including (a) norms for operating outside normal disciplinary boundaries, (b) additional time and effort needed to engage in interdisciplinary collaborative efforts, (c) perceptions of a hierarchy of disciplines, (d) felt lack of support from departments and institutions for engaging in these collaborations, and (e) adjustments to teaching practices.

Faculty find working across disciplines challenging when compared to their typical disciplinary collaborations. Lindvig and Ulriksen (2019) conducted a review of peer-reviewed articles that examined interdisciplinary teaching practices in higher education. Although the reviewers acknowledged inconsistent definitions of interdisciplinary teaching, they confined their review to any teaching involving faculty combining content across disciplinary boundaries, teaching that involved more than one instructor, or faculty presenting content in such a way that students were required to work across disciplines. Faculty noted that interdisciplinary teaching often connoted students' active involvement with the content, such as via projects or group work, over more traditional lecture formats. Overall, faculty perceived interdisciplinary collaborations as outside their typical disciplinary roles. In another study, McNair et al. (2015) found that 15 engineering and scientists at three universities felt out of their disciplinary comfort zone when working across disciplines. This work required them to think differently about terminology and content within their disciplines and its relevance and relationship to other disciplines.

Another issue noted by researchers concerns the additional time and effort required of faculty when they engage in across-discipline activities, a challenge that impacts faculty involvement in these efforts. In a study of 38 faculty, Lattuca (2001) found that faculty read more widely around the different disciplinary perspectives when doing across-discipline work. They also indicated that across-discipline curricular development and teaching required more preparation time and patience as faculty worked through different interpretations of terminology and language and spent additional time in conversations with colleagues negotiating issues of content, methods, and diverse perspectives and approaches. Weber et al. (2013) found similarly for secondary STEM educators. Even if there was pressure to collaborate, educators perceived a lack of time and resources (e.g., workload, technology) to successfully engage in working with faculty across disciplines to create curricula that incorporated aspects of those disciplines.

A third issue noted in the research involved faculty members' perception of a hierarchy of disciplines when they engaged in across-discipline approaches. Gardner (2013) conducted a study of 25 faculty at one university involved in an across-discipline research and teaching project related to sustainability issues. Gardner found that nearly all faculty who participated worked with other faculty from similar disciplines, paradigmatically, either with others in the "soft" disciplines (e.g., social sciences and humanities) or the "hard" disciplines (e.g., natural sciences). When faculty did cross boundaries, they experienced difficulties. Among the challenges were differences in language, methodology, and felt-confidence in their disciplines' essential contributions. Overall, the faculty noted two different camps, those in physical sciences and those in social sciences. Faculty in the social sciences indicated feeling marginalized and dismissed by faculty in the physical sciences. As a result, they felt less confident about their discipline's place in the sustainability initiative than science faculty, who saw their disciplinary perspectives as essential to the project. Similar findings were reported in a study by Bouwma-Gearhart (2012b) around STEM education improvement initiatives that brought STEM faculty and those from the education sciences into collaborations at five institutions to revise curricula and instruction in lower-level STEM courses. Findings revealed that some STEM faculty were skeptical of the value of education faculty's contributions and expertise. Education faculty noted feeling their disciplines and expertise were undervalued. These perceptions faded over time as the STEM and education faculty groups worked more together.

A fourth issue related to faculty engagement in across-discipline collaborations involved faculty members' perceived lack of departmental and institutional support. Faculty concerns included a lack of financial support for their efforts and a lack of other rewards such as promotion and tenure considerations (Lattuca, 2001; Lindvig & Ulriksen, 2019). In another study that looked at across-discipline collaborations, Wright et al. (2015) detailed a five-year curriculum development project focused on sustainability issues at one large university. Throughout the project, across-discipline faculty communities engaged in workshops to develop curricula centered around five themes. Their study found that administrators and academic leaders were critical to providing resources and leadership that supported and sustained the momentum. In comparison, faculty's across-discipline activities that did not receive such support struggled to successfully integrate across-discipline efforts into the institution's systems and processes. Once the initial project was over, across-discipline collaborations and the resulting efforts ended (Wright et al., 2015). In the same study noted above that looked at the integration of STEM disciplines, Weber et al. (2013) found similarly for secondary STEM educators that across-discipline collaborations were not encouraged either through policy or by other types of administrator support.

Finally, research has uncovered positive changes to teaching practices due to across-discipline collaborations. Based on their own experiences, Clark and Ashurst (2018) found that faculty engaged in across-discipline collaborations incorporated a more problem-focused approach to their teaching that did not rely on solely transmitting disciplinary knowledge. Additionally, across-discipline collaborations pushed faculty to adopt more diverse, inclusive ontological and epistemological worldviews that focused on societal problems and complex systems and included various academic perspectives beyond their disciplinary perspectives. These collaborations led to faculty co-producing knowledge that was not compartmentalized within only one discipline. Finally, across-discipline faculty collaborations involved changing the traditional use of space, time, materials, and technology in teaching to a more flexible and dynamic arrangement that might include changing configurations of classrooms, the use of new technology, or a change in delivery modes. In a yearlong study, Hurney et al. (2016) also noted changes to teaching via across-discipline faculty collaborations. Fourteen faculty from the humanities, natural science, and social sciences were engaged in interdisciplinary course development and teaching related to sustainability issues. They perceived their teaching practices changed due to teaching courses with other faculty, including learning new teaching techniques and technology tools. They also felt that integrating sustainability content enhanced their course redesign by providing real-world relevance, awareness, and engagement for students.

The Need for Research Concerning Transdisciplinary Curricula Development and Course Planning

While the above research may help predict the experiences of faculty engaged in across-discipline work to create transdisciplinary curricula, there is an obvious need to explore such novel work, including the affordances and tensions that faculty may perceive (Jahn et al., 2012; Oliver & Hyun, 2011). Given the growing interest and support to reform STEM education, specifically, we are especially in need of documentation of the challenges and successes of transdisciplinary curricular development initiatives to inform future STEM education-focused initiatives that may promote faculty working across disciplines. Moreover, in light of the complexity and realities of faculty work (e.g., autonomy, competing professional demands) and their organizations (e.g., departmental and institutional norms and practices), and how these impact initiatives, we are specifically in need of faculty perceptions of initiatives promoting this work. This research can provide both faculty and those working to support them with a roadmap to successfully develop transdisciplinary curricula (Lattuca et al., 2004).

Methodology

Paper Focus and Research Questions

Our qualitative study investigated faculty's experiences from diverse disciplines, primarily sciences, business, and other social sciences, as they collaborated to develop a transdisciplinary curriculum module to teach across their courses. Our study highlights the affordances and tensions participants perceive as they collaborate to develop the transdisciplinary curriculum, including relevant institutional norms and structures.

Specifically, we explored the following research questions:

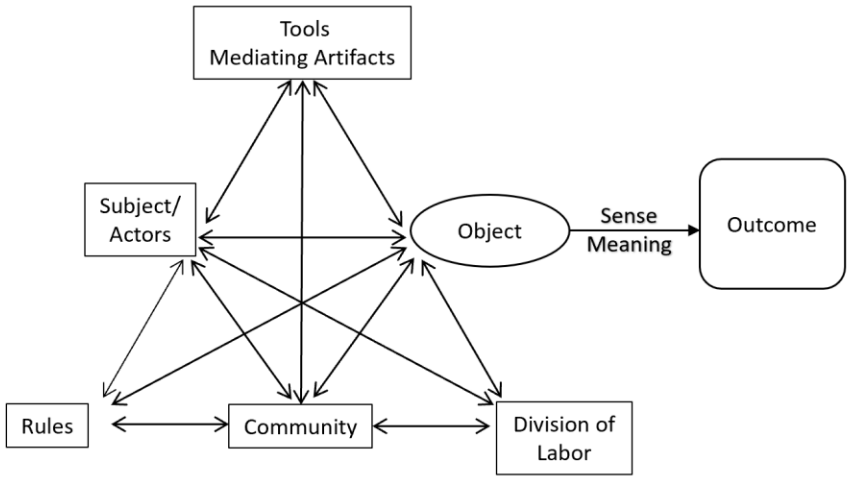
1) What motivates across disciplinary faculty to engage in a project to co-develop a transdisciplinary curriculum for implementation in their classes?
2) What challenges and concerns do participants experience in curriculum creation and implementation plans?
3) What affordances support their curriculum creation and plans for implementation and any alleviation of their challenges and concerns?

This study begins to fill the gap in knowledge about the realities that faculty from different disciplines may experience in developing transdisciplinary curricula regarding topics notably at the intersection of the natural and social sciences. We discuss implications and recommendations for transdisciplinary curricula proponents who may support faculty in these endeavors and see the value for postsecondary students. Specifically, we detail implications of our research to inform faculty members, professional developers, administrators, and other education leaders, including discussing strategies that can support and encourage such innovations.

Conceptual Framework

We conceptualize faculty and leader co-development of a transdisciplinary curriculum as an activity system within a larger social context (Engeström, 2001). *Cultural-historical activity theory* highlights various factors impacting human action. Specifically, we rely on second-generation cultural-historical activity theory (Engestrom, 2009), which recognizes six elements (or nodes) interacting in a social system. In this conception, activity systems include *subjects* that represent individuals or groups engaged in interactions within the system, influenced by structures and processes around them. For instance, subjects may be faculty or leaders engaged in interactions as they work towards the desired objective (see Figure 1). 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). These can be material or conceptual and may involve language, disciplinary methods, cultural artifacts (e.g., symbols), and technologies. For instance, faculty may use other faculty members' syllabi in planning a new course. By directing the mediating artifacts or tools towards the desired *objective* or *object,* the actors can produce *outcomes* (Engeström, 2001). For instance, faculty may create a new curriculum (i.e., the object) as part of a new sequence of courses or build students' understanding of crucial knowledge (i.e., outcomes).

Figure 1
The Structure of an Activity System



Note. Interpretation of cultural-historical activity theory (Engstrom, 2001).

Subjects do not work in isolation but within a *community,* which consists of others who influence or collaborate with the subject working toward objects and outcomes (Engeström, 2001). For instance, a faculty member's community might consist of administrators, other faculty, and students. *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. For instance, higher education institutions may have formal rules associated with faculty workload and accreditation requirements and more informal norms of interactions around teaching, some explicit and others implicit. A *division of labor* delineates the various actions towards 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). For instance, faculty may make most decisions around their teaching methods (how they teach within their courses), but they may not have as much authority in deciding which courses they teach or, even, their content.

Subjects perceive these aspects of the system, including relationships *within* and *between* them, as degrees of affordances towards realizing the object and outcome. Tension 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. Tensions can provide opportunities for learning or inspiring redesign of the activity as actors seek to overcome or address them (Alexander & Hjortsø, 2019; Engeström, 2015). For instance, faculty may find ways to redesign their courses or programs to include more content that crosses disciplinary boundaries and provides students with relevant content.

We use cultural-historical activity theory per its promise in calling attention to the complexity of the social activity, as that done by faculty, situated within multi-faceted contexts, disciplines, and higher education organizations (e.g., programs, departments, institutions). In this case, we analyze professional work around a task, faculty co-development of a transdisciplinary curriculum, cognizant of relevant affordances and tensions within a larger pertinent context (Foot, 2014). In doing so, we provide new knowledge about the realities of a novel faculty-related activity system that is seldom witnessed yet sure to grow in prominence. Per understanding of affordances and tensions impacting this important faculty work, we offer suggestions for others attempting or promoting faculty development of transdisciplinary curricula, including attention to relevant contextual elements and their interconnectedness.

Overall Research Design

We used a phenomenological approach to capture individuals' lived experiences about a phenomenon (Creswell, 2014), in this case, the co-development of a transdisciplinary curriculum around sustainability problems that could later be taught in participants' upcoming courses. A phenomenological approach is consistent with cultural-historical activity theory, both based on a social constructivist worldview that assumes individuals create meaning of their experiences, including meanings around certain other objects or things in their world (Creswell, 2014).

Study Context and Participants

The NSF-funded project brought faculty and project leaders from three institutions together to develop and implement a transdisciplinary curriculum module around sustainability issues that could be taught in multiple courses across institutions. Seven project leaders across three universities recruited twelve teaching faculty (hereafter just *faculty* versus *leaders*, with these groups, combined referred to as *participants*) from science, business, and other social science disciplines. See Table 1.

The three universities involved in the initiative include *Institution A*, where the project's head leader, the Principal Investigator, worked along with two other project leaders and four faculty. Institution A is a private university in the Northeastern United States that serves approximately 4,000 predominantly undergraduate students majoring in business education. Institution A is classified *master's colleges & universities: larger programs* within the Carnegie Classification of Institutions of Higher Education (Indiana University Center for Postsecondary Research, 2017). Lacking separate schools or colleges, Institution A is structured as departments, including departments under the larger category or *business* (e.g., Accountancy, Finance, Marketing). Other departments are arguably interdisciplinary, such as natural and applied sciences (e.g., biology, chemistry, environmental sciences), global studies (e.g., political science, public policy, international studies), and English and media studies (e.g., creative writing, literature, film studies, cultural studies, media production).

Two leaders and four faculty worked at *Institution B*, a large public university in the Midwestern United States that serves approximately 13,000 undergraduate students. Institution B is classified as a public *doctoral university: high research activity* within the Carnegie Classification of Institutions of Higher Education (Indiana University Center for Postsecondary Research, 2017). It has an organizational structure that includes seven degree-granting colleges or schools that offer more than 60 undergraduate majors. It also has 39 academic departments (e.g., English, finance, history, mathematics, environmental studies) often found in large research universities and various interdisciplinary institutes that foster interdisciplinary research and teaching collaborations around particular topics such as the environment, languages, and the earth sciences. Although there is a stated focus on collaborating across disciplines in these interdisciplinary institutes, most of the disciplines represented are within similar disciplinary fields, for example, environmental, energy, and water studies. 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, four-year liberal arts college in the Midwestern United States, with approximately 1,900 full-time undergraduate students. Institution C is classified as a *baccalaureate college: arts and sciences focus* within the Carnegie Classification of Institutions of Higher Education (Indiana University Center for Postsecondary Research, 2017). It 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. Institution C has been engaged in a departmental realignment process in recent years 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 (see Table 3). 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 co-developed a one-to-two week transdisciplinary curriculum module containing a common exercise, course-specific exercises, and assessments. Three pre-workshop sessions were held over the first seven months in preparation, each lasting approximately an hour. 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 pre-workshop sessions, the faculty shared their perspectives while leaders guided discussions. The faculty chose water quality and health/wellness as the wicked problem of sustainability. The leaders used a backward design approach (Wiggins & McTighe, 2005) to guide faculty in designing the curriculum.

Participants began the five-day workshop by identifying student learning outcomes for their selected topic to guide their content development. In addition to determining content related to water quality and health, participants designed two major activities for students. First, students were to develop a stakeholder map showing nitrogen in the water cycle and then engage in a role-playing exercise in which they attend a fictional town hall meeting and present various stakeholder groups' perspectives. Also, during the five-day workshop, faculty developed formative and summative assessments to utilize with students. As this was the main objective of work up to this point, we note that project work was successful. Participants interacted via virtual platform technologies, including a) the Zoom video conferencing platform for small/large group interactions, sharing screens and PowerPoint presentations, and a chat feature, b) a project management platform that provided collaborative workspaces for communication, storing resources, and working together, c) 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).

The seven project leaders consisted of two deans, three department chairs, and two professors across the three institutions, distributed across science and business disciplines. Leaders served as the point of contact for their institutions. Their goal was to support faculty in developing a transdisciplinary curriculum module and coordinating across the three institutions. They were also similar to the faculty in their intent to teach the curriculum module within their courses. Local learning communities, consisting of participants, were created within each institution to support participant collaborations. Table 1 shows the institutions and number of participants in their major discipline areas. 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 other social sciences, anthropology/sociology, and information/communication. The 12 *faculty* participants are identified as pseudonyms F1-F12. The seven project leaders are identified with pseudonyms L1-L7.

Table 1
Disciplines and Institutions of Project Leaders and Faculty

Disciplines	Institution A		Institution B		Institution C	
	[1]PL	[2]Faculty	PL	Faculty	PL	Faculty
Science: Chemistry, Geology, Biology, Environmental Studies	2	2	1	2	1	1
Business: Economics, Finance/Accounting, Entrepreneurship	1	1	1	2	1	2
Other: Social Science, Information/Communication	0	1	0	0	0	1

[1]PL (project leaders) n = 7; [2]Faculty n = 12; N = 19.

Table 2 shows the level of experience that faculty and leaders reported having with transdisciplinary curriculum and instruction at the beginning of the project via survey. Two project leaders and six faculty (n=8) reported having little to no transdisciplinary curriculum development experience. One project leader and four faculty (n=5) reported having some transdisciplinary curriculum development experience. Four project leaders and two faculty (n=6) reported having significant experience or more than most faculty with developing transdisciplinary curriculum development.

Table 2
Self-reported Experience with Transdisciplinary Curriculum Development and Instruction

Experience	[1]Project Leaders	[2]Faculty	Total
Little to no experience	2	6	8
Some experience	1	4	5
Significant experience (more than most faculty)	4	2	6

[1]n = 7 project leaders. [2]n = 12 faculty. N = 19.

Data Collection and Analysis

Over the twelve months, we collected data through interviews, a survey, observations of meetings, and faculty work documents. See Table 3 for a description of the activities, data collected, and timeline. The first author took observation notes at all leader planning meetings, pre-workshop sessions, and the five-day workshop, which the second author also observed. We used an observation protocol during the 5-day workshop to be more systematic. While doing so, we attempted to document participants' actions as they collaborated to develop the transdisciplinary curriculum. We also collected documents created by the participants at all meetings and the workshop. The authors utilized the observations and documents to make sense of the interview and survey data (detailed below).

Table 3
Description of Activities, Data Collected, and Timeline

Activities	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Project leader interviews (n=7)		X										
Faculty pre-interviews (n=12)			X									
Faculty post interviews (n=11)												X
Survey of leaders and faculty (n=19)				X								
Project leaders planning meetings (n=6)	X		X		X		X		X		X	
Faculty pre-workshop sessions (n=3)	X				X		X					
5-day curriculum development workshop								X				

We conducted semi-structured interviews with the seven leaders in month 2 of the project (see Appendix A 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. We also asked the leaders to describe how faculty might struggle to work across disciplines and what issues they saw with inter-institutional collaborations. The results of our interviews with the leaders helped to inform the pre-workshop interview (hereafter pre-interview) protocol for faculty, which was administered in month 3 after the first pre-workshop faculty session. We asked faculty to describe their experiences with developing transdisciplinary curriculum activities and their curriculum development and teaching practices in the pre-interviews. We also asked them to describe affordances and barriers they might experience in this initiative and the initiative's potential to influence faculty work and organizational structures at their institutions. We conducted post-workshop interviews (hereafter post-interviews) with faculty in month

12, after the development activities were completed yet before faculty taught the transdisciplinary curriculum module. We asked questions about the benefits and challenges of being part of the project, expected changes to how and what is taught related to sustainability, and developing a transdisciplinary curriculum. We used open-ended interview questions for all the interviews that encouraged reflective responses (Creswell, 2014). (See Appendix B for faculty pre-post interview questions.)

We had interviews transcribed verbatim before transferring them to Dedoose coding software for qualitative analysis. The first author initially created inductive codes from a first read of the leader interviews' verbatim transcripts, drawing perspectives from interviewees' own words towards grounded interpretations of answers to interview questions (Auerbach & Silverstein, 2003). When encountering new findings, the analyst revised codes and reapplied to previously analyzed interviews (see Appendix C for final codes and definitions). During the coding process, the first author also created memos (Montgomery & Bailey, 2007) to capture ongoing analysis throughout the process. The first author shared and discussed codes and memos with the second author to support and enhance the accuracy of the analyses. Summary documents from each analysis were shared with the leaders to ensure the accuracy of findings and to inform changes to the project strategy regarding project goals.

We developed and administered a survey to participants following the interviews to collect additional data (month 4). Survey questions asked about department climate, beliefs, and teaching practice norms, as well as faculty members' professional networks. Based on insights gained from the interviews in months 2-3, we included questions that further probed participants' perceptions of experiences developing transdisciplinary curricula, including working with other faculty and norms within their departments (see Appendix D for survey questions). We compiled survey results and performed descriptive analysis, including the range of scores, percentages, and totals. This paper only reports on survey items that investigated similar items as the interview questions.

We used interviews and the survey to build and confirm findings and themes, building our analysis's trustworthiness (Creswell, 2014). Interview transcripts, as typical in a phenomenological approach, were privileged. Per the tenants of cultural-historical activity theory, we use the following descriptors to provide a range of our findings' prevalence: *a few* means claimed by 1-5 participants; *several* 6-10 participants; *a majority* 11-15; and *most* 16-19. A second method we utilized to ensure the analysis's trustworthiness was to spend a *prolonged time* with the study participants to develop an in-depth understanding of the case (Creswell, 2014, p. 202). The primary author, over twelve months, interviewed all participants, conducted the survey, and attended all participant meetings (including all five days of the workshop), during which she wrote observation notes and collected relevant documents. A third method, *peer debriefing*, was used to ensure trustworthiness (Creswell, 2014, p. 202). The second author supported the development of the interview, survey, and observation protocols, wrote detailed observations at the workshop, and participated in debriefing and data analysis sessions with the first author throughout the collection, coding, and data analysis. Finally, we used *member* *checking* (Creswell, 2014, p. 201-202) of our findings 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. We felt the leaders were well-positioned to provide adequate input given their role in the curriculum's co-development 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 do not make any generalizability claims per a phenomenological approach, given individuals' lived experiences around a novel activity system. As well, our research participants may bring bias to the results of this study. Project leaders recruited faculty at each of the institutions. Faculty volunteered to participate in this project; 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. The authors may have also contributed bias in unanticipated ways as teaching faculty and curriculum developers. Finally, due to COVID-19 constraints, we had to conduct all of our investigations through virtual means, which may have influenced the data we could collect and, ultimately, our findings.

Findings

Motivations of Interdisciplinary Faculty to Engage in Co-Development of Transdisciplinary Curricula

Faculty expressed multiple reasons for participating in the project, including a desire for (a) meaningful collaboration around teaching with peers from other disciplines; (b) enhancement of their knowledge around sustainability; (c) improvement of teaching practices and curriculum, including for promotion and tenure considerations; and (d) creation of a curriculum that would benefit their students via novel and meaningful content.

Meaningful Collaboration Around Teaching with Peers (in Other Disciplines)

In pre-interviews with faculty, several indicated excitement for their participation per the meaningful collaboration around teaching it would allow. In doing so, faculty often spoke of a typical lack of faculty collaborations around teaching, especially across disciplines. 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 (F7) 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 skillsets and different ways of looking at the world….that's exciting for me.*

In the post-interview, this same business faculty (F7) confirmed his earlier perceptions and further confirmed the novelty of such faculty collaborations. He saw his participation as potentially laying groundwork for future interdisciplinary collaborations.

> *For me, at least so far, 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. Then, down the line, you just never know how those connections might prove to be valuable.*

An accounting faculty (F10) also relayed typically feeling “siloed” concerning teaching, even within her department. She saw the project as an opportunity to work with other faculty from business subdisciplines and those outside the business department.

> *I do find that sometimes 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. So when there was an email that came out asking if people are interested, that was definitely one of the reasons.*

A science faculty (F1) compared the project to other professional development opportunities of which he has been part. Overall, he felt the project could be more meaningful and exciting than other opportunities he had been part of, allowing faculty to learn around the topic of sustainability as they worked on developing the curriculum, which he 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. So I think it's really exciting. It builds this collaboration and the energy that goes on there. We are all pushing towards a common goal. I mean, we may not get there, but we're all really trying and our efforts and hearts are in the right place to really do it.*

Specifically, faculty indicated a desire to work with “like-minded” others that had an interest or commitment to creating experiences for students that would have them creating knowledge across disciplines. An economics faculty (F6) 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.*

Enhancement of 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 (F9) saw value in learning from science faculty and felt he could share such knowledge with his 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, or some of the other things that the other people in the cohort will bring to the discussion. I'll just be able to interject into my classes a lot of that interesting context to what we're talking about.*

An economics faculty (F6) anticipated that her participation would allow her to engage more with sustainability issues, specifically that she perceived to be more concrete than some of the disciplinary problems of her typical focus as an instructor. She expressed a need to work with those outside of her discipline to develop practical understandings around sustainability.

> *I'm an economic theorist, which means that I oftentimes 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 (F2) indicated it was important to learn more about sustainability issues per a personal commitment to be a good steward for the natural environment. He said:

> *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. I forget who it was that referred to it as spaceship earth, but I mean, I think it's important to take care of this spaceship around.*

Improvement of Teaching Practices and Curriculum, Including for Promotion and Tenure Considerations

Several faculty members spoke of a desire to improve their pedagogy generally. An engineering faculty (F5) spoke of how he anticipated the project activities and development process would allow for this. He said:

> *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 (F8) perceived this project would improve his teaching to be less philosophical and academic to be more directly applicable to his students. He thought his teaching's interdisciplinary nature was something he always tried to bring to students, but this project allowed him a specific way to do that, which would benefit his teaching and his students. He said it this way:

> *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. I'm excited that this project will have a very direct, very specific means of doing so [enhancing teaching], because sometimes as we teach, conversations can be philosophical or academic and not have a lot of direct applicability for students.*

One economics faculty (F9) anticipated that his participation in the project and his resulting teaching of the module would impact the curriculum that he would implement and his teaching methods. He said:

> *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. It will potentially change the way that I continue to teach these classes.*

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

> *[Engaging in this project] is definitely another motivator [for promotion and tenure] 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.*

Creation of Curriculum that Would Benefit Students

Most faculty and project leaders perceived the transdisciplinary curriculum would benefit students in providing them new understandings and perspectives. A business faculty (F5) anticipated that his 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. An economics faculty (F3) anticipated the curriculum would provide her students content not covered in a textbook and real-life illustrations and other content applications. She stated it this way:

> *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 (F6) anticipated that in each class that taught this module, students would get to experience concepts informed by other disciplines, disciplines that they otherwise may have little engagement with.

> *The main benefits to students is that they are going to also get this access to interdisciplinary teaching. In every single class they're in of these 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.*

A leader (L5) also perceived the curriculum would allow students to see wicked problems from multiple disciplinary perspectives, which would help students understand the complexity of such problems and view the problem holistically as they attempted to address it. She said:

> *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.*

A science faculty (F8) hoped his students would benefit from a curriculum that wove together science and business to better prepare them for their workforce futures. He said:

> *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.*

Challenges and Concerns Participants Experience in the Curriculum Creation and Planning

Participants experienced challenges and concerns in both the curriculum's creation and in planning for/envisioning the teaching of this. These challenges and concerns included (a) challenges with organizational norms and practices; (b) concerns with navigation around norms, language, and practices given the cross-disciplinary collaboration; (c) realities of the virtual environment in which project activities happened; (d) ambiguity and sense of productivity around group work; (e) suitability of the transdisciplinary curriculum module for courses; (f) perceptions of increased time and revisions to workload; and (g) faculty confidence (or lack of) around teaching transdisciplinary curriculum.

Challenges with Organizational Norms and Practices

A majority of participants perceived departmental and institutional norms as challenging to transdisciplinary curriculum development and teaching. One of the leaders (L1) identified content “territorialism” as one concern for departments. He said:

> *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.*

A science faculty (F4) mimicked 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 (L3) saw such departmental attitudes as an institutional challenge due to who participates in improvement initiatives versus not. She relayed that education improvement initiatives were somewhat typical on campuses. Reflecting on past experiences with these, she maintained that for successful and significant changes to attitudes and norms, an initiative needed to reach and influence more than just a few people. She said:

> *[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.*

An economics faculty (F7) also detailed constraints at the university level and its culture regarding faculty creation and transdisciplinary curricula. He tied these structures to faculty members' weighing their time constraints and knowledge of the work they are typically rewarded for and not. He said:

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 (F5) perceived a lack of support by university administrators, conceptualized as a disconnect between what administrators said they wanted to happen and what they supported. He said:

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 TD 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. So to me that's a little bit of a frustration.

Survey data indicated around half of the participants (9/19, 47%) felt administrators often do not adequately support faculty involvement around pedagogical innovation (see Table 4). Only around a third of respondents (7/19, 37%) felt that administrators adequately supported faculty members in their departments to work with other faculty and create curricula spanning disciplines.

Table 4
*Faculty and leaders' perception of administrators' support and involvement in their department**

Faculty members in my department…	Somewhat or Strongly Disagree		Somewhat or Strongly Agree	
	n	%	n	%
are adequately supported by administration to engage in innovative instructional practices	9	47	10	53
are adequately supported by administration to work with other faculty to develop interdisciplinary curriculum (e.g., workload, promotion, and tenure considerations)	12	63	7	37

*N =19. Percent rounded to nearest one.

Several leaders were particularly attuned to the complexity of developing and sustaining transdisciplinary collaborations within departments and institutions, particularly concerning budgetary constraints made worse in the current pandemic.

This comment by a leader (L6) was made before the COVID-19 pandemic became a reality but showed the general challenges faced by those trying to innovate. She felt that the resources for transdisciplinary work were the most limiting, including financial and "recognition" resources, themselves primarily based on a department-based resources-allotment structure. She stated:

> *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.*

Concerns with Navigation Around Discipline-related Norms, Language, and Practices

A majority of participants spoke of concerns with 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. To contextualize the interview data, survey data indicated that less than half of participants indicated that faculty members in their department taught with other faculty (9/19, 47%) or implemented transdisciplinary curriculum and instruction (8/19, 42%) (see Table 5).

Table 5
*Faculty and Leaders' Perception of Other Faculty Members in their Departments**

Faculty members in my department…	Somewhat or Strongly Disagree		Somewhat or Strongly Agree	
	n	%	n	%
teach with other faculty	10	53	9	47
implement transdisciplinary curriculum/instruction	11	58	8	42

*N =19. Percent rounded to nearest one.

A leader claimed that teaching transdisciplinary curricula could be perceived as too outside these norms, too difficult for faculty, allowing them to dismiss attempting it easily. He stated it this way:

> *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.*

Another leader (L2), reflecting on faculty teaching transdisciplinary curricula specifically, stated that he hears faculty's concern about the discomfort they perceive in teaching outside one's discipline. He said:

> *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 his interdisciplinary research experience, the information/communication instructor (F2) anticipated faculty would face different norms and terminology. They would need to form a common language to articulate their perspectives across the disciplines. He said:

> *But I think what comes up in general, because a lot of research projects I do are interdisciplinary too, is 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 (F8) also discussed concerns with language and terminology associated with different disciplines, stating:

> *Speaking the same language with collaborators I think is another major challenge. Speaking the same language as people in business or in other programs will be challenging in terms of curriculum development.*

This same science faculty (F8) also anticipated navigating different teaching practices, assuming different practices were more typical in specific disciplines than others. He said:

> *I talk a lot with friends of mine here in different departments, and I've talked about lecture preparation and, for me, how long it takes me to prepare one lecture for one of my biology courses compared to somebody in math or somebody in foreign languages. They [practices] vary widely.*

Realities of the Virtual Environment in Which the Curriculum Creation Happened

The reality of the work challenged a majority of participants due to the novel coronavirus. This reality was the virtual environment the work had to be done within, including 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 they felt allowed them to process conversations and more fully explore concepts. One leader (L5) acknowledged the value in typical exchanges between structured activities in face-to-face environments. She felt the loss of those more "organic" exchanges, which also translated to a loss of sharing expertise and knowledge. She did not think these exchanges could be replicated in a virtual environment. She said:

> *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 (L2) felt similarly. He 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 the virtual environment and the activities in that environment were occasionally overwhelming due to the technology's challenges. A faculty member (F2) wrote in an evaluation at the end of one of the workshop days that he felt challenged in following and finding all of the materials and missed collaborating and brainstorming on a whiteboard or other in-person technology. He stated it this way:

> *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 (F2) 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 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 (F3) felt like she was getting tired of the virtual environment even though she felt like they were productive at the same time. She 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.*"

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 components of the module 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. A business faculty (F10) 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 with these group work times collectively towards the final product. A social science faculty (F11) expressed frustration on an evaluation:

> *It did feel less productive having all 3 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.*

A science faculty (F4) felt their group had been very productive in the breakout sessions, but she was frustrated that the progress that was made in the smaller groups did not get built upon when the larger groups met. She felt that lost or unincorporated ideas and concepts left her unclear about what the module would look like and how she would incorporate it into her class. She 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.*

An economics faculty (F6) also pointed to the perceived loss of critical elements in the module that had been previously discussed in the smaller groups. She talked about the two main activities proposed in the module, a stakeholder map/visualization exercise, and the role-playing activity. For the visualization exercise, she felt like one of the breakout groups had not adequately developed the activity, even though it was something that had been discussed numerous times in previous days. Her other concern was with the pedagogical strategies associated with teaching the role-playing exercise, which she 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 seemed underdeveloped.*

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 (F8) spoke about how he would have to shift topics and concepts around within the course to fit the module. He was concerned that his course did not present content via case studies or via division into something resembling modules. The module would require him to adjust to this new curriculum structure and develop a plan to still cover all of the other content that he needed to cover.

> *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 (F4) expressed her concern that the module's content may not fit well with the other content in her course. She thought students might see the module as disconnected from the other topics they studied. She talked about it in this way:

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

A business faculty (F3) conveyed her concerns with the curriculum module's complexity in relation to her introductory level economics course. She was concerned that students might not have the academic preparedness to succeed with it, especially in light of time constraints over the course term. She said:

> *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.*

Perceptions of Increased Time and Revisions to Workload

A few faculty mentioned increased time or workload needed for collaborations, especially those altering established curriculum. A faculty in business (F7) identified the challenge of adjusting curriculum and teaching that may have been in place for many years. He stated:

> *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.*

An economics faculty (F9) saw extra time and workload in planning and delivering curricula that deviated from course textbooks. He stated it this way:

> *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.*

A chemistry faculty (F1) indicated that administrators had a role in alleviating some of these concerns and typical institutional limitations around faculty co-teaching. He stated it in this way:

> *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 co-teach courses. And co-teaching is not, "I'm going to teach the first five weeks of the class and then you're going to teach." That's not co-teaching. 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. So I think that's a real challenge. That's a structural challenge that has to get addressed.*

Faculty Confidence Issues Around Teaching Transdisciplinary Curricula

A few faculty spoke of concerns about their confidence (or lack of) in teaching transdisciplinary curriculum and working with other faculty to develop transdisciplinary curriculum. One social science faculty (F11) explained how she was confident with her syllabus and curriculum design. However, she was less confident about creating a curriculum not squarely in her discipline. She implied discipline-based perspectives about sustainability-related issues that might impede her and others' abilities. She also did not feel confident designing a curriculum used by other faculty in another classroom outside her discipline. She talked about it this way:

> *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 confidence about how I might go about scripting something or how learning should happen.*

The survey, conducted before the curriculum development workshop, seemed to confirm that a few participants lacked confidence in teaching a transdisciplinary curriculum and working with other faculty in different disciplines to develop a transdisciplinary curriculum (see Table 6). These data stand in opposition to all 19 faculty and leaders surveyed, having indicated that they were confident in *teaching* (overall) and felt able *to create and implement curricula with others* (overall).

Table 6
*Faculty and Leaders' Confidence with Teaching and Curriculum Development**

	Somewhat or Strongly Disagree		Somewhat or Strongly Agree	
	n	%	n	%
I feel confident in teaching.	0	0	19	100
I am able to work effectively with others to create and implement curriculum.	0	0	19	100
I feel confident in teaching transdisciplinarily.	3	16	16	84
I am able to work effectively with others to create and implement transdisciplinary curriculum.	2	10	17	90

*N =19. Percent rounded to nearest one.

Affordances that Support Curricular Creation and Plans for Implementation

Most faculty perceived affordances that supported their curriculum creation and plans for implementation. A majority of faculty perceived the project leaders afforded them significant support for creating the curriculum through the leaders' facilitation of the development process, their co-development of the curriculum, and their skillful use of technological tools. Several faculty perceived their participation, and the work that resulted could begin to alleviate faculty-specific barriers and organizational norms noted above, including future related efforts. Faculty perceived this project would allow them to (a) alleviate the concerns of other faculty regarding the creation and value of the curriculum, (b) increase their confidence related to teaching and working across disciplines, and (c) increase innovation in teaching practices.

Project Leaders Afforded Support for Curricular 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. A leader (L1) made this comment at the beginning of the final day of the 5-day development workshop. He 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. He saw the transdisciplinary perspectives as the module's strength and acknowledged that as the most challenging part of the work.

> *Again, we'll talk about how the common exercise [transdisciplinary curriculum module] and how the whole module comes together. And as we open this up, one of the things that I just want to remind you of is: we've had so many good ideas that have come up. 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.*

An information/communication faculty (F2) appreciated how the leaders had organized the workshop. He 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. A science faculty (F12) described the leaders' skillful 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 Co-Developers of the Curriculum.

Although the leaders wanted to give faculty as much control and ownership over the curriculum content and activities as possible (observation notes from the second leader planning meeting), the leaders acted as co-developers, making comments about what they saw happening throughout the curriculum development process. Here we see a comment that one of the leaders (L2) made to the faculty during a large group discussion on day four of the workshop. The faculty worked for two days developing content and activities and were struggling with how to pull the different components together. Leader 2 praises what the faculty have accomplished to that point. He describes what faculty have developed thus far as a set of activities that students would do, such as describing the movement of materials or the potential health and ecosystem impact of chemicals. He asked faculty if that is enough or if they want students to explain or analyze questions related to the larger problem of clean water or its impact on social and economic systems. He states:

> *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, chemical clothes, social systems, economic systems, and so forth?*

A business faculty (F7) reflected on the leaders’ role toward developing a successful module in the post-interviews. In particular, this faculty saw the leaders' role in co-developing 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. He said:

> *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 (F12) 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. He saw the leaders' efforts as necessary in creating something that faculty could use. He wrote this comment:

> *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 Afforded 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 (F2) 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 (F8) acknowledged the benefits of the online format as a tool to keep the meeting focused and on target, even though he acknowledged the exhaustion of collaborating in this way.

> *Some of the benefits of that format though is 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 Other Faculty Reservations 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. An economics faculty (F3) 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.*

A science faculty (F4) also saw the curriculum resulting from the project potentially helping to alleviate other faculty members' concerns around courses' worth. She felt that infusing transdisciplinary curriculum into her courses may show the importance and possibility of teaching science to students majoring in business. She thought this might change the perspectives of some of the senior faculty in business, which she acknowledged was 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.*

Increased Confidence in Teaching and Working Across Disciplines

In the post-interviews, a few faculty expressed an increase in their confidence in teaching and working across disciplines. A business faculty (F10) confirmed the value of the novel experience of collaborating with other faculty that the project afforded. This faculty spoke about how the experience alleviated her concerns about how she would teach the transdisciplinary curriculum in her course, the increase in her understanding of teaching per these interactions, and precisely how she 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 (F10) stated that she had increased her awareness about sustainability issues per her participation and indicated that this focus helped her imagine work across disciplines. She said: "*It definitely increased my personal awareness about sustainability and just the idea of doing things that are across discipline.*" An entrepreneurship faculty (F7) also saw the benefit of connecting with other faculty that would not have happened without this project. He, 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.*

Increased Innovation Around Teaching Practices

In the post-interviews, a few faculty perceived the across-disciplinary collaborations inspired increased innovation around their teaching practices. This science faculty (F4) said participation in the project allowed her to innovate around her teaching, and in a way, she 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 she could now utilize in her class.

> *But I think that [developing TD 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 (F3) saw the new curriculum module as a catalyst for redesigning a new approach to her introductory economics courses, which she thought would help students not feel overwhelmed by a large amount of information. She felt that designing her courses around themes related to wicked problems would help students see the connection between economics and sustainability. She acknowledged that the new approach would be a challenge and a way to redesign and teach her courses.

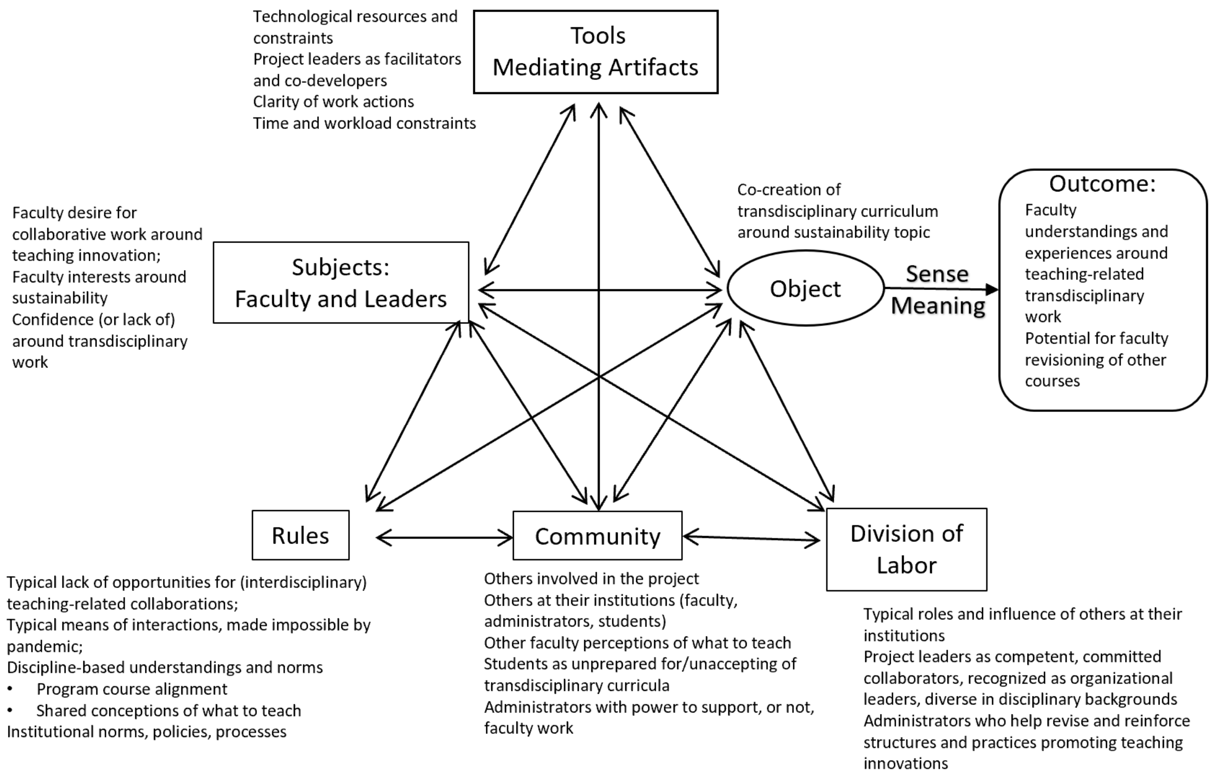
> *It really helped challenge me to think of a new approach to teaching my course. So what I'm launching this in is Principles of Microeconomics, so it's the very first econ course that a lot of my students are taking. And it's sort of this overwhelming deluge of information that we try to explain to 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, what I did is 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

There is growing recognition of the importance of engaging postsecondary students in transdisciplinary experiences, which can help students become more scientifically and technologically literate, generally, and heighten their ability to solve modern socioscientific problems. Given these problems are not solvable through the lens of a single discipline and the academy's structures and practice-norms, across-disciplinary faculty collaborations are essential to create these student experiences (Austin, 2011). There is reason to anticipate such work challenging for faculty, including limited previous research around faculty working across disciplinary boundaries. Research around interdisciplinary faculty development of transdisciplinary curricula, specifically, is virtually non-existent. Herein we shared results of an exploratory study of one project (an *activity system*) that brought faculty from the natural and social sciences (*subjects* in the system) to develop a curriculum module around a topic related to sustainability issues (the system *object*), arguably an area concerning the most pressing socioscientific problems of our time. Utilizing a framework of cultural-historical activity theory, we documented relevant factors important to this work, including affordances of the project (system *mediating artifacts*) and other factors in their larger professional social contexts, including disciplinary and organizational norms and structures (the system *rules*, *community*, and *division of labor*). (See Figure 2).

Figure 2

The Activity System: Factors Influencing Interdisciplinary Faculty Transdisciplinary Curriculum Development



The findings discussed above suggest several complex factors impacting participants' across-disciplinary co-development of the transdisciplinary curriculum. This complexity is partially per our use of cultural-historical activity theory, which focused attention on the interactions of participants' work. These included long-standing norms and practices that may reinforce and aggravate difficulties in achieving their goals. Such diagnosis of a system can be powerful to inform future work in illuminating ways to eliminate or minimize tensions impeding their activities and potential for change. System participants themselves can learn about and help resolve tensions to bring an activity system to a state where the participants can accomplish the object and their outcomes (Engestrom, 2009). As well, those less involved directly in the activity can help to alleviate tensions. This section summarizes and discusses this novel and complex activity system findings and suggests recommendations for promoting successful transdisciplinary curriculum planning and teaching.

Faculty as Motivated Subjects Per Typical Lack of Professional Opportunities

Our analysis found that faculty were motivated to participate in the project per its potential for meeting their professional development needs. These included a desire to create a curriculum around sustainability issues (the project's main focus) and underlying relevant motivations. First, faculty seemed to understand the need for, and desired, professional development that can improve their pedagogy around transdisciplinary issues, including creating a curriculum to utilize and enhancing their pedagogical content knowledge (how to enact this for meaningful learner development). Faculty were especially motivated around sustainability issues, a problem that they felt both personal and professional interest around. As a complex problem to understand and teach, they entered the project to meet needs around their knowledge and pedagogical practice limitations.

Perhaps these findings are not too surprising, given that our interviews were of faculty and leaders who had committed to participate in the project. Nevertheless, we note the importance of these findings for two main reasons: 1) they highlight faculty realities relevant for such work and their participation more generally in education innovation initiatives, and 2) these findings might indicate multiple levers for other faculty members’ participation in similar initiatives. Surely there is growing evidence from the work of others that faculty are motivated to innovate around their teaching to better serve their students (e.g., Barth et al., 2007; Bouwma-Gearhart, 2012b), including those in the STEM disciplines, often targeted by postsecondary education improvement initiatives (Austin, 2011) and sometimes assumed to disregard or under-privilege (good) teaching and efforts to secure this (Bouwma-Gearhart, 2008; Hora & Ferrare, 2013). STEM faculty can recognize their pedagogical weaknesses and, even tenure-line faculty at research universities, seek out means to increase their knowledge and skills (Lattuca, 2001). At times, faculty (again, even STEM faculty at research universities) have seen the promise of their innovation around teaching and learning as “counting” in their promotion and tenure bids (Bouwma-Gearhart, Ivanovitch, et al., 2018). Faculty motivations have been linked to a typical lack of opportunities to develop their pedagogical knowledge and skills, including collaborations with other faculty, which are also typically limited (Bouwma-Gearhart, 2008) and those involving others from other disciplines (Lindvig & Ulriksen, 2019). Our research supports these findings, ultimately relevant mediating artifacts and rules within the system of investigation across a diverse array of faculty. And these findings back up others’ assertions of the relevant levers that may inspire other faculty's teaching-related innovation work. These levers include helping faculty to understand pedagogical knowledge and skills as developed and not innate (Lattuca, 2001, 2005), the offering of multiple improvement initiatives with support for their participation in them (McGregor, 2017), and seeing faculty as partners in their pedagogical development who have expertise and support to contribute to their peers (Austin, 2011, Henderson et al., 2011).

Specifically, our findings concern an activity system that faculty might perceive to be particularly daunting. Others may assume it is particularly hard to support, that is, faculty's collaborative work with those from other disciplines to create transdisciplinary curricula around wicked socioscientific problems. Indeed, few faculty have experience doing such. No doubt, as a result, before in-depth participation in the project, participants expressed concerns about their confidence/competence in creating and implementing transdisciplinary pedagogy. However, other professional realities motivated them to do such work nonetheless, and these findings may suggest levers for encouraging faculty participation in similar efforts. For instance, some faculty desired to work with others to make changes/improvements to their pedagogical practices. Proponents of transdisciplinary pedagogy can offer and advertise collaborations in this space, including making known the participation of respected peers within and across disciplines. The potential of transdisciplinary work counting in promotion and tenure considerations may additionally motivate some faculty, and administrators can work with faculty governance structures to help make this a reality.

Other faculty may be motivated to do teaching-related transdisciplinary work to learn more about specific socioscientific issues, to better their understanding and that of their students. Our findings suggest that the particular subject of focus may motivate faculty learning around professional and personal reasons. Problems of timely social interest, for instance, climate change and threats to social justice, might motivate faculty to first engage in collaborating with others around pedagogical innovations and transdisciplinary work specifically, in comparison to initiatives promising professional development around more general evidence-based teaching practices, for instance. Indeed, there may be potential for capitalizing on various faculty motivations to secure their participation in the very complex work of creating transdisciplinary curricula around socioscientific problems.

At the same time, those not yet doing this work may broadly anticipate their professional realities as impediments to it. While we only investigated the perceptions of faculty already committed to co-developing transdisciplinary curricula with others across disciplines, our participants also identified constraints that may impede faculty participation to engage in such work and success in doing so. We must further consider these constraints and support their success in light of these, to which we now turn.

Promoting the Success of Faculty Members' Interdisciplinary and Transdisciplinary Work

Before in-depth participation in the project, participants expressed concerns about their confidence/competence in creating and implementing transdisciplinary pedagogy and "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, including thoughts on important content and ideas around how students might best learn content. In some cases, these perspectives were voiced as challenges and concerns, including how suitable or appropriate the curriculum module would be in their courses, where the transdisciplinary curricula would fit in the sequencing of content, and how they would make it relevant to the rest of the course content.

For some faculty, incorporating the module in their courses was daunting enough; others (mis)alignment with other courses and faculty in their programs was concerning. Faculty also were concerned with how their new transdisciplinary curriculum and teaching might create tensions with other faculty and administrators in their departments. 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 potentially problematic when coordinating with other business faculty who were not incorporating the transdisciplinary curriculum. We note some alignment of these findings with other researchers investigating across-disciplinary faculty collaborations. Several participants anticipated that other faculty within their departments would perceive their involvement in such an initiative as operating outside the normal academic rules, including typical disciplinary and departmental boundaries. As described by Lindvig & Ulriksen (2019), there was a concern for the "othering" of their interdisciplinary activities, which can have negative professional ramifications for those being "othered."

As well, faculty relayed that such work collaborations would not be considered a high priority by many departmental administrators. Given the extra time and effort to develop and incorporate transdisciplinary curricula (see also Lattuca, 2001), faculty seemed to perceive a risk to participating in such endeavors, especially without additional resources or policy changes. The absence of these can act as deterrents for faculty involvement in teaching-related initiatives and innovations (McClam & Flores-Scott, 2012), including interdisciplinary collaborations (e.g., Bouwma-Gearhart, 2012a; Wright et al., 2015). Further tensions involved faculty's anticipated perceptions of the transdisciplinary curricula by their students (i.e., 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.

The above concerns implicate both administrators' and faculty leaders' work and support. In fact, leaders in this project, to a certain extent, anticipated some of these concerns that faculty would bring to the experience. In these cases, we observed leaders addressing these concerns head-on during discussions with faculty as they introduced and guided project activities. We also observed leaders documenting their thoughts about implementing the transdisciplinary module (and past transdisciplinary curricula) in their courses, which may have served as illustrations for others to emulate. Overall, we recommend leaders sensitive to such concerns and overall to faculty realities allowing space for faculty to anticipate, voice, and help problem-solve around such problems. Leaders may specifically need to remind other faculty of the typical student push-back 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.

For their part, administrators (i.e., department chairs, deans, provosts, and presidents) can help alleviate faculty concerns for operating outside normal disciplinary and organizational rules, including rules perceived by students, to influence policies, practices, and cultures that value teaching-related transdisciplinary efforts. Administrators, working with faculty governance structures, might help teach-related transdisciplinary efforts, like other teaching innovations, be conceptualized positively in any teaching evaluations. Administrators have a crucial role in framing teaching innovations as, ultimately, student success and retention issues. Administrators can also help secure resources of faculty time or stipends that might allow faculty to work on curricula creation during times when they have more time to devote, which may also send a powerful message to faculty and departments prioritizing such work. Further, they can help revise promotion and tenure structures and norms to allow for or even promote teaching-related transdisciplinary efforts as valued faculty activity, shown to be valued for other faculty work across disciplines (McGregor, 2017). Administrators can be extra strategic in planning these supports to mitigate "content territorialism" that participants noted as an impediment to implementing transdisciplinary curricula. Policies and practices may also inspire faculty to envision and strategize the offering of transdisciplinary experiences alongside curricula instrumental for students' understanding of the essential disciplinary knowledge and ways of knowing. Through targeted messages, administrators can communicate with faculty that transdisciplinary curricula and instruction do not dilute disciplinary norms and practices. However, it can serve as an avenue to strengthening disciplinary content and relevance and help provide more effective programming for students. Interestingly, some participants were hopeful that their participation in the project, and its results, might help to change departments, programs, and even institutions, to understand better and privilege such work.

Leaders among faculty may be especially well-positioned to increase the chances of transdisciplinary curricula being incorporated into program courses.

Potential leaders of similar endeavors should also note the multiple affordances that our research participants claimed fostered their transdisciplinary curriculum creation. Some affordances seemed more technical, such as the various tools that leaders selected and demonstrated, for project collaborations (e.g., Zoom, Google Docs, and Slack). Faculty found these helpful for co-creation and capturing ideas and content, exchanging the pertinent information, and general project management. However, interactions with these tools also created some tensions. Faculty struggled at times with locating information among the plethora of resources. As mandated by the COVID-19 pandemic, solely working within these structures was felt by all as impediments. Somewhat still unfamiliar electronic interactions replaced familiar, face-to-face ones. Overall, faculty and leaders largely bemoaned the loss of chats in hallways between breaks, conversations over dinner, and nonverbal cues that could have likely lessened some tensions, such as the unclear goals of some group work activities in “break out rooms” within the Zoom platform, exacerbated by the novelty of the more extensive process overall. Still, although faculty and leaders missed the face-to-face interactions that an in-person workshop would have provided, they were no less engaged in the process in the virtual environment and their desire to make the project a success. 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 utilized.

Overall, competent, committed, and recognized project leaders were seen as the most significant affordance of the transdisciplinary work. Faculty leaders can build trust and credibility with faculty. Additionally, those representing diverse disciplines may be positioned to help address and resolve tensions around different disciplines' language, norms, and practices, like those observed in this project. It may be important to note the various disciplinary backgrounds that the leaders represented across the sciences and business fields. As leaders, they may have also set a tone that alleviated some tensions that could have otherwise presented. Past research has shown a "disciplinary hierarchy" of sorts that can happen in some interdisciplinary faculty collaborations (e.g., Bouwma-Gearhart, 2012a; Gardner, 2013). Faculty are discouraged from fully participating if they perceive their disciplines (and their expertise) are not represented or recognized as meaningful in the 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 the natural sciences 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 pedagogy expertise may have more success recruiting and supporting skeptical faculty. Leaders with experience with previous across-discipline collaborations and who show a willingness to enact co-developed 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 co-developers of transdisciplinary curricula may have helped ensure success.

Although we do not have data to test this currently, we hypothesize that the realization of a ready-to-teach curriculum module may end up playing out as one of the most significant affordances for faculty implementation of transdisciplinary experiences for students. This initiative may stand in contrast to the results of many other teaching-related improvement initiatives. Often faculty struggle to turn their professional development experiences, including the research-based "best" practices promoted, into pedagogical practice (Austin, 2011; Bouwma-Gearhart, 2012a; Henderson et al., 2011). We are left wondering if a resulting curriculum, inclusive of faculty and student activities, may be somewhat of a "sweet spot" in ensuring the initiative impacts practice. 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. Such expansive shared experience, peer support, and notably continued accountability may further help ensure the project's success. Our future research will explore these things.

Conclusions

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). Proponents of such work, including disciplinary and initiative leaders and administrators, should continue to identify those that may be willing, even excited, to do such work, as well as levers to motivate others currently less enticed. These levers may include helping to connect faculty wishing to work with others around a topic that they find appealing for various reasons, in this case for both their students and their better understanding of pressing societal issues. As more and more faculty work to create and implement transdisciplinary experiences for students, discipline-based norms and perspectives towards teaching-related transdisciplinary work may also change. 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.

Research investigating faculty from multiple disciplines developing transdisciplinary curricula is still rare (Fam et al., 2018; Oliver & Hyun, 2011). 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 critically important investigations that consider the complexity of systems in which faculty function. We encourage others to share their experiences, to collectively work to further faculty development and resulting curricula and instruction that benefits students' development as problem-solvers around some of our society's most pressing socioscientific concerns.

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Manuscript One - Appendices

Appendix A

Interview protocol for project leaders

1. I'd like to know more about your position at [name of institution] AND on the project. Specifically:
    1. Briefly describe your role and responsibilities in your current position at your institution.
    2. Can you tell me about YOUR role and responsibilities on the grant, including in comparison to others?
3. The Project has the following three goals: 1) curriculum development, which is to produce, implement, improve and disseminate novel transdisciplinary curriculum modules focused on sustainability problems that can be used in a wide variety of STEM and business courses, 2) faculty perspectives, which is to build capacity to create and implement sustainability curriculum and instruction by changing the perspectives and norms of faculty around transdisciplinary work and collaborations, and 3) student learning, develop measures to assess student learning and demonstrate improved student learning outcomes.
    1. What affordances or constraints regarding these goals might individual faculty encounter?
    2. What affordances or constraints regarding these goals might departments/programs encounter?
    3. What affordances or constraints regarding these goals might your institution encounter?
    4. What affordances or constraints regarding these goals might you encounter in your position?
4. Do faculty targeted by this Project at your institution interact/work regularly with others concerning issues of teaching and learning? [if yes], Please provide details regarding
    1. Who? in the same discipline/department/program or others?
    2. How typical are these interactions?
    3. What encourages or discourages these interactions?
    4. In what ways do you anticipate the project influencing these interactions in any way?
5. Describe the general climate [beliefs, attitudes, outlook] at your institution, or relevant programs/departments (to the grant) concerning teaching innovation and teaching improvement work?
    1. To what extent are faculty expected/encouraged to create their own curriculum? Transdisciplinary curriculum?
    2. Create curriculum with others? Transdisciplinary curriculum?

    3. Assess the efficacy of their curriculum and instruction, and make changes accordingly?
    4. Given a-c, what do you think the Project might help change or support?

6. What might a meaningful curriculum that emanates from this project look like, that could meet the project's learning goals for students?
7. What does a successful faculty work group look like, that has the potential to create this meaningful curriculum?
8. We know that faculty may struggle to work across disciplines to create curriculum. We also know that faculty struggle to create curriculum that is truly transdisciplinary.
    1. What challenges do YOU think the faculty YOU will work with will have with respect to these things?
    2. Tell me how this project may overcome some of these challenges?
9. In what ways might this project change the way your organization operates or sustains the changes that are made?
10. Do you foresee any issues related to working across institutions?

Appendix B

Interview protocol for faculty
Pre-interview protocol for faculty:

1. I'd like to know more about your position at [name of institution]. Specifically:
    a. What is your official title?
    b. Briefly describe your role and responsibilities in your current position.
    c. What disciplines have you taught previously or that you are teaching now? How many years have you taught at this institution or others?
2. I'd like to hear about your engagement with the "sustainability curriculum" project. Specifically:
    a. What motivates you to participate in this project? [probe re Promotion & Tenure and other "rewards"]
    b. What expectations do you have for how this project will impact you or your work/responsibilities?
3. Please describe any teaching experiences you have had that involve you teaching content that spans different disciplines, including with other educators?
    a. What disciplines did this span?
    b. How did disciplines interact, meaning what did the curriculum/instruction look like for students and for the educators?
    c. Who is involved?
    d. What benefits have you noted?
    e. What challenges have you noted?
4. This "sustainability curriculum" project has three (3) major goals related to faculty perspectives, curriculum development, and student learning. I will briefly paraphrase each goal and then ask you some questions related to each one of them. Specifically:
    a. One goal is related to curriculum development, which is to produce, implement, improve and disseminate novel trans (or cross) disciplinary curriculum modules focused on sustainability problems that can be used in a wide variety of STEM and business courses. [Ask i, ii, iii questions]
    b. The second goal is related to faculty perspectives, which is to build capacity to create and implement sustainability curriculum and instruction by changing the perspectives (attitudes) and norms (practices) of faculty around trans (or cross) disciplinary work and collaborations. [Ask i, ii, iii questions]

c. The third goal is related to student learning, which is to develop measures to assess student learning and demonstrate improved student learning outcomes. [Ask i, ii, iii questions]
    i. What opportunities or challenges might faculty encounter in achieving these goals?
    ii. What opportunities or challenges might you encounter in your teaching towards achieving these goals?
    iii. What opportunities or challenges might your department/ university encounter in achieving these goals?

5. Can you briefly describe or tell me about how you plan for a unit or module or topic in a course...how do design/decide on what/how to teach when a unit or module or topic in a course?
6. Please describe your typical assessment strategies for assessing student learning? To what extent do the results of your student assessment impact your future teaching?
7. Is there anything else you would like to comment on or talk about?

Post interview protocol for faculty:
Questions:

1. What benefits, if any, have you realized being part of this project?
2. Describe any challenges you have experienced in being part of this project?
3. If not addressed in #1 or #2, probe for any changes to:
    a. developing transdisciplinary curriculum concerning sustainability
    b. perspectives (attitudes) and norms (practices) of faculty around trans (or cross) disciplinary work and collaborations
    c. assessing student learning
4. Of the benefits and challenges you have identified, is there anything more related to the summer workshop? Or the LLCs?
5. Has this experience changed what and how you teach related to sustainability? If so, in what ways/how?
6. Has, or will developing the TD curriculum module change how you teach? If so, in what ways? (if needed elaborate on instructional methods, curriculum order, etc)?
7. Have you implemented the common exercise or gathered any data yet regarding associated student learning? If so, what did you learn, if anything? If not, what are your thoughts about the "finished" module that you received from the leaders?
8. What, if anything, would you like to see changed or done differently in this project moving forward, or others like it that bring faculty across disciplines together to develop TD curriculum?

9. What haven’t I asked you about that you think would be important to know about your experience if I was coaching other faculty considering doing this?

Appendix C

Codes and Definitions

Achieving Project Goals: The Sustainability Curriculum project intends to develop and implement transdisciplinary curriculum around issues of sustainability, to be used in a wide variety of STEM and business courses, via collaborative work of interdisciplinary faculty, namely those from science and business disciplines. Interdisciplinary faculty will be brought together via various activities (local learning communities) to work on creating, implementing, and eventually testing/revising the curriculum they create, towards an improved curriculum.
Challenges to Faculty: Challenges that faculty may encounter in working to create, develop, implement, and assess transdisciplinary curriculum
Challenges to Organization (structures): This code includes any challenges to departmental or organizational structures. This could include policies, procedures, practices, norms, or attempts to maintain the status quo
Opportunities for Faculty: This includes any opportunities that the project may offer to faculty towards creating, developing, or implementing sustainability curriculum modules
Opportunities for the Organization: This includes any opportunity that this project provides to the organization that is considered a positive development.
Assessment of Student Learning: This code is related to any statement about assessing student learning or assessment of course/program or institutional goals related to accreditation or other external pressures. This can also mean assessing learning within the module.
Benefits for Students: This code is tied to any mention of benefits for students related to the project. This can include among other things, improved critical thinking skills, ability to see multiple perspectives, career development and more preparations for future jobs. Aspirational goals for students are also included with such things as making the world a better place.
Climate (beliefs, attitudes): This code involves any mention of the climate, which includes beliefs and attitudes at the institution. This also includes mentions of culture, which includes practices or long held norms
Faculty Collaborations: This code includes references to faculty working in a collaborative way with other faculty either within their discipline or across disciplines. This can include encouraging collaborations or issues that discourage collaborations.
Perceived Goals of the Project: This code includes the project goals that PIs perceive this project is trying to accomplish. These goals may or may not align with the stated goals in the grant proposal or may reflect the PIs interpretation of those goals.
Perceived Role of PIs of Project: This code is based on a question that asked the PIs to describe their roles and responsibilities related to the project.
Policy, Procedures, and Practices: Any policy, procedures, practices that are related to the project, this could include tenure and promotion, changing reward structures, etc...

Resources and Budget Issues: Any mention of how this project might impact budget or resource allocation in any way, either during or after the grant to sustain the work.
Affordances: This code is used for any mention of what the environment offers the individual or group
Curriculum Development (transdisciplinary): This code refers to any reference to creating or developing curriculum and can include any discipline
Disciplines (subject): This code refers to the person or discipline (e.g. STEM disciplines, business, social science or others)
Pedagogical Practices: This code refers to any mention of teaching or students related to developing the curriculum
Tensions: This code refers to any contradictions or tensions that might exist within or between individuals and groups.
Virtual Environment (tools): This code relates to any reference to the virtual environment especially as it relates to Zoom conferencing platform, Slack messaging platform, google docs, SERC website, or other tools broadly that exist online. (e.g. websites, resources, documents)
Wicked Problem: Any reference to the wicked problem, particularly as it relates to cross disciplinary communication or coordination

Appendix D

Survey Protocol

Section No. 1: Background Information

1. What is your institution?
2. What is your main affiliation at your institution? (check all that apply)
    a. Instructor/ lecturer (non-tenure-track faculty member)
    b. Tenure track (not yet achieved tenure)
    c. Tenure track (achieved tenure)
    d. Assistant Professor
    e. Associate Professor
    f. Professor
    g. Administration
    h. Other (Please specify)
3. Roughly how many years have you been affiliated with your current institution?
    a. 1 - Less than 1 year
    b. 2 - 1-5 years
    c. 3 - 6-10 years
    d. 4 - 11-15 years
    e. 5 - 16 years or more
4. Please specify your discipline(s), that you research and teach in.
5. Please indicate your percentage of time allotted (by contract) to the following activities
    a. Teaching
    b. Advising
    c. Research
    d. Service
    e. Outreach
    f. Administration
    g. Other (Specify)
6. Roughly how many years have you been teaching as instructor of record of courses?
    a. Less than 1 year
    b. 1-5 years
    c. 6-10 years
    d. 11-15 years
    e. 16 years or more
7. How would you rate your past experience with interdisciplinary teaching?
    a. No experience
    b. Some experience

   c. Significant experience (more than most faculty)
8. How would you rate your past experience working in professional learning communities
   a. Little to no experience
   b. Some experience
   c. Significant experience (more than most faculty)
9. Reflecting back on recent past years, approximately how many hours a week did you spend on the following teaching-related activities during a typical teaching term?
   a. Under 1 hour
   b. 1-5 hours
   c. 6-10 hours
   d. 11-15 hours
   e. 16 or more hours
      i. Teaching in class or lab
      ii. Planning for instruction
      iii. Talking with others about teaching and learning
      iv. Office hours
      v. Grading or providing students' feedback on their work
      vi. Considering performance data (e.g., exam or clicker question results) to inform my teaching or my students' learning
      vii. Considering findings from educational research to inform my teaching or my students' learning

Section No. 2: Teaching Practice

10. Do you interact regularly with others concerning issues of teaching and learning?
    a. Less than monthly or never
    b. Occasionally - most months
    c. Regularly - most weeks
11. Where do these interactions happen? (check all that apply)
    a. Program-level meetings or events
    b. Department- or college-level meetings or events
    c. Curriculum committee meetings or events
    d. Disciplinary conferences
    e. Events run by a center for teaching or comparable unit
    f. In individual offices or smaller meeting rooms
    g. Other (Specify)

Section No. 3: Networking

12. In this section, we will ask you to tell us about people with whom you communicate about teaching and learning issues or activities over the course of a typical academic year.
13. What is the person's primary relationship to you?
    a. Colleague in your department
    b. Colleague outside your department, but still at your institution
    c. Colleague affiliated with a Center for Teaching and Learning or similar entity
    d. Graduate student or postdoc at your institution
    e. Colleagues from outside your institution
    f. Family
    g. Other Please Specify: ________
14. What is the highest frequency of interaction with this person over the course of a typical term/semester?
    a. Less than one interaction per term
    b. About one interaction per term
    c. Multiple interactions per term
    d. Multiple interactions per week
15. What issues of teaching and learning do you discuss with this person?
    a. Teaching methods - how to teach
    b. Teaching materials and technologies - how to teach with what
    c. Curriculum - what to teach
    d. Curriculum timing - when to teach what
    e. Assessment - how to measure the impact of teaching
    f. Other grading issues
    g. Student motivation issues
    h. Student diversity issues
    i. Policy or accreditation issues
    j. Teaching issues related to promotion and tenure
    k. Research/scholarship on teaching and learning
    l. Interdisciplinary curriculum and instruction
    m. Curriculum and instruction regarding sustainability

Other (specify)

Sections No. 4: Beliefs

Please indicate your level of agreement with the following items

a. Strongly Disagree
b. Somewhat Disagree
c. Somewhat Agree
d. Strongly Agree

16. I feel confident in teaching.
17. I feel confident in teaching interdisciplinarily. Interdisciplinary is defined as combining subjects together in new ways or working between different academic disciplines.
18. I am able to work effectively with others to create and implement curriculum.
19. I am able to work effectively with others to create and implement interdisciplinary curriculum.
20. I regularly collect student learning data that informs my teaching.
21. I regularly analyze student learning data that informs my teaching.
22. I am effective in analyzing student learning data that informs my teaching.
23. I feel that assessing student learning in an interdisciplinary curriculum will be more challenging than doing so in the discipline in which I typically teach.
24. I am confident in engaging in professional learning communities. A professional learning community is defined here as a group of educators that meet regularly, share expertise, and work collaboratively to develop curriculum, improve teaching skills, and work to improve the learning experiences of students

Section No. 5: Climate

Faculty members in my department/unit….

a. Strongly Disagree
b. Somewhat Disagree
c. Somewhat Agree
d. Strongly agree

25. Discuss teaching with colleagues
26. Share teaching resources with colleagues
27. Develop teaching resources with colleagues
28. Are encouraged by department administrators (e.g., department chair) to work with colleagues about their teaching
29. Utilize teaching development services available on campus
30. Teach with other faculty
31. Implement interdisciplinary curriculum/instruction
32. Are slow to accept innovations promoted by teaching improvement efforts
33. Are adequately supported by administration to work with other faculty to develop interdisciplinary curriculum (e.g., workload, promotion and tenure considerations)
34. Are adequately supported by administration to engage in innovative instructional practices
35. Are open to administrators involvement in curriculum decisions
36. Perceive administrators as focused on enrollment/graduation numbers over instructional improvement issues

CHAPTER 3 – Manuscript Two

Uncovering the Complexity of STEM Faculty Perceptions About Successful Students, and Their Teaching Strategies that Support Them

Cindy Lenhart, Jana Bouwma-Gearhart, & Benjamin Ewing

Abstract

Multiple factors are known to influence student success in higher education. Barriers to postsecondary success for underrepresented STEM students are numerous and well documented. We detail an exploratory study of STEM faculty notions of successful students and the instructional practices they employ to cultivate student success. We use a conceptual framework of educators' perceptions, teaching practices, and student engagement to analyze faculty's perceptions of their students that may inform and influence their teaching practices. This framework also allowed us to uncover potentially unknown and unintended perceptions, practices, and structures that may implicate larger social structures that result in inequities experienced by many individuals in STEM education. We found faculty perceive a range of characteristics and factors indicative and predictive of student success. Faculty also described a wide range of instructional strategies they perceived as effective. We offer insights into STEM faculty practices and expectations that assume and encourage groups traditionally successful in STEM while also highlighting implicit and hidden faculty expectations that may position women, racial/ethnic, and other underrepresented groups as unsuccessful in STEM. This paper adds to the limited research that explores STEM faculty perceptions of their notions of successful students and the relationship between those perceptions and their teaching practices.

Introduction

Improving Student Success in Higher Education

Multiple factors influence student success in higher education (Kuh, 2003). *Student success* is broadly defined as accomplishing academic goals (e.g., passing exams, classes, earning degrees, developing understanding and applications regarding knowledge). Postsecondary faculty members play a crucial role in students' success in higher education (Endo & Harpel, 1982; Umbach & Wawrzynski, 2005). Regular implementation of evidence-based instructional practices (EBIPs), such as active learning strategies, problem-based activities, and group work, has shown to be critical to the success and persistence of students in STEM (science, technology, engineering, and mathematics) disciplines (Austin, 2011; Freeman et al., 2014). STEM courses with active learning-based activity designs correlate with higher rates of students' success than traditional lecture-based methods (Haak et al., 2011). Other research has found that EBIPs afford additional benefits for STEM students from disadvantaged and underserved backgrounds and female students in male-dominated fields (Haak et al., 2011; Lorenzo et al., 2006).

Yet, research also shows that STEM faculty have not implemented EBIPs improvements to the degree that many have hoped for (Henderson et al., 2011). STEM faculty members' understanding, adoption, and adaptations of EBIPs is still limited and challenging (Bouwma-Gearhart et al., 2018; Dancy et al., 2016; Fisher et al., 2019; Henderson et al., 2011). Reasons for the slow adoption of EBIPs are numerous but include organizational cultural norms, structures, and practices (Hora et al., 2017; Kezar, 2012). We know that faculty typically receive little training and professional development regarding their teaching during typical training as graduate students (Bouwma-Gearhart, 2008; Bouwma-Gearhart et al., 2007; Bouwma-Gearhart et al., 2018). Once they become faculty, institutional policies and procedures motivate them to privilege their research over teaching and teaching-related improvement efforts (Bouwma-Gearhart, 2008; Brownell & Tanner, 2012).

Other barriers to adopting EBIPs are a lack of knowledge around them (Patrick et al., 2016) and professional development opportunities and release time to learn about and plan for them (Bathgate et al., 2019; Borda et al., 2020). Additional barriers to EBIPs implementation included faculty members who felt the need to cover content and perceptions that lecture-based instruction best accomplished that goal (Borda et al., 2020). Bathgate et al. (2019) confirmed that science faculty favor lecturing over many EBIPs, and encounter students' resistance to EBIPs. Brownell & Tanner's (2012) literature review concerning barriers to faculty pedagogical changes has generally confirmed these findings. Although Hora (2015) has sagely cautioned against assuming STEM faculty members' "lecture" is ineffective and not aligned with EBIPs, there seems to be a consensus that STEM faculty may over-rely on lecture as practice and at the expense of implementing more effective teaching practices.

One avenue of research links EBIPs with student *engagement,* itself an indicator and predictor of student success in higher education (Kuh, 2009a; Tinto, 2010). *Engagement,* defined as a student’s psychosocial actions and characteristics concerning learning activities, includes their behaviors, emotions, and cognition (Kahu & Nelson, 2018). The link between engagement and student success is well confirmed. Some researchers view engagement as the single most significant predictor of students' academic success, including for underrepresented populations such as women, students of color, and other marginalized groups (Kuh, 2009a; Tinto, 1998). Engagement is often wrapped with a goal of increasing the use of EBIPs by STEM faculty (Bouwma-Gearhart et al., 2018; Koretsky et al., 2016). The ability to foster and support diverse student success via their engagement roots many interventions targeting faculty members' pedagogical improvements (Kahu & Nelson, 2018; Kuh, 2009b).

Such focus may help alleviate the impact of a plethora of barriers that stand in the way of students' success from underserved and underrepresented groups in the STEM disciplines (Pierszalowski, 2019; Pierszalowski et al., 2018). Generally, notions of activities in STEM courses as gender-, ethnicity-, and race-neutral meritocracies lead to unwelcoming cultures that privilege white and male students over others (Blackburn, 2017; Johnson, 2007; Shapiro & Sax, 2011). At the postsecondary course and program level, language and tone in such course syllabi can normalize masculinity and disenfranchise those of other genders. As such, women can perceive STEM courses as competitive and selective, discouraging collaborative work and reinforcing lower confidence in their STEM discipline participation (Shapiro & Sax, 2011).

Women of color may perceive the content presented in their undergraduate courses as decontextualized from their real-world experiences (Johnson, 2007). They can encounter faculty expectations that are not verbalized or not noticeable around student actions that enhance their success, such as asking questions and consulting faculty during their office hours (Johnson, 2007; Shapiro & Sax, 2011). In her extensive literature review in 2019, Pierszalowski confirmed many of these findings. She also identified barriers related to an institutional focus on surface-level strategies that had little impact on underrepresented students' persistence in STEM. These barriers included a lack of faculty incentives to mentor marginalized student groups and faculty perceptions that students lack capacity and competence.

Indeed, barriers to postsecondary success for underrepresented STEM students are numerous and well documented. These include climate and culture, more attributable to organizations of people and their interactions and symbols, and things more indicative of faculty members' teaching—the curriculum they use, their teaching methods, and their syllabi. Overall, active learning-based activities and courses have been shown to correlate with increases in the number of students completing science-related degrees, particularly for first-generation students and those from educationally and economically disadvantaged groups (Haak et al., 2011).

What We Know About the Role of Educators Perceptions Impacting their Teaching Practices

Additional barriers to implementing evidence-based instructional practices, like active learning, are faculty perceptions (i.e., conclusions, judgments, insights, beliefs) about teaching and learning, including their teaching practices and their students' realities. We know faculty hold numerous perceptions about their teaching, and these perceptions impact their classroom actions (Fang, 1996; Padilla & Garritz, 2015). For instance, in a study of 24 STEM faculty engaged in teaching professional development activities, Mataka et al. (2019) found a positive linear relationship between STEM faculty perceptions about educators' role, how students learn, and their ultimate decisions around the content and instructional practices they implemented. Faculty who perceived knowledge as conveyed by faculty experts implemented teacher-centered practices such as lecture-based instruction. Addy et al.'s study (2015) of 25 U.S. postsecondary science education faculty found similar findings. Faculty who viewed themselves as facilitators and guides were more likely to adopt and use learner-centered teaching practices. Perhaps not surprisingly, then, initiatives meant to improve postsecondary STEM education often focus on revisions to faculty perceptions (Bouwma-Gearhart et al., 2016; Gess-Newsome et al., 2003; Henderson et al., 2011; Weber et al., 2013). This goal seems well justified, as much scholarship reports on changes to educator perceptions around teaching and learning in light of professional development opportunities. For instance, Kane et al. (2004) found that when science faculty were encouraged to reflect on their perceptions about teaching, specifically their decision-making processes, analysis of teaching performances, and a critical reflection of their actions, they were more likely to develop and implement EBIPs.

However, improvement initiatives' success relies on accurate reads of faculty members' perceptions about teaching and learning, from which to develop strategies and tactics that may be meaningful (Bouwma-Gearhart & Aster, 2021; Bouwma-Gearhart & Collins, 2015; Bouwma-Gearhart et al., 2018; Mataka et al., 2019). Specifically, limited studies have examined and reported on faculty perspectives of their students and what they think helps to ensure their students' success. In one study, Gandhi-Lee et al. (2015) found that 27 STEM faculty described successful students as having personality traits such as curiosity and a strong work ethic, key academic traits such as problem-solving, and good written and oral communication skills. They also found faculty described successful students as having affective qualities such as positive attitudes and interest in and engagement with STEM issues. On the flip side, faculty also perceived a lack of mathematical knowledge and skills as significant obstacles to students' success. Padilla & Garritz (2015), in a study of ten university STEM faculty, found that faculty perceive their students as mostly passive learners (i.e., not engaged in their learning) and lacking in fundamental skills (e.g., efficient reading or writing skills).

This research is indeed helpful in uncovering faculty perceptions of successful students. However, we need more to confirm and extend these findings, including an investigation of how faculty perceptions may determine how and the degree to which they support student success. Without insight into faculty perceptions of their students, those successful and not, professional development experts and others cannot implement improvement initiatives that attend to the impact of faculty perceptions of students and the subsequent influence on teaching practices. We also know little about how they may reduce, or exacerbate, differences in success across student groups in postsecondary STEM. Achievement gaps and lagging completion rates that persist in some student groups in the STEM disciplines (Haak et al., 2011; Lorenzo et al., 2006) suggest that we need to scrutinize faculty perceptions of students and related teaching practices. Given the inequities that still exist for underrepresented students in postsecondary STEM programs and careers (Shapiro & Sax, 2011; Solomona et al., 2005), we must better uncover the realities of faculty well-positioned to have a significant impact on the success of diverse students.

Without understanding this relationship, faculty and their leaders lack the knowledge that is key to implementing practices and structures that may specifically improve student success for underrepresented groups in STEM (Kuh, 2009b; Tinto, 2010).

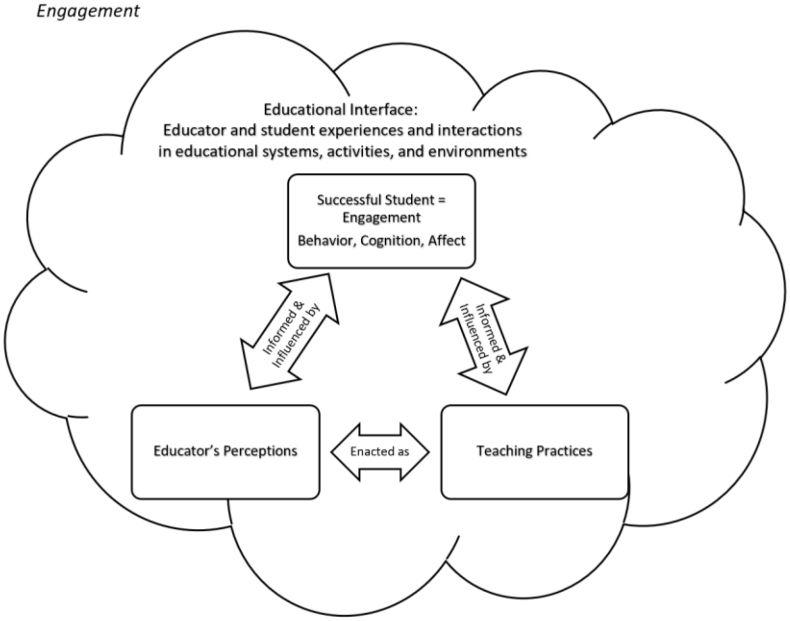
This paper adds to the limited research that explores STEM faculty perceptions of their notions of successful students and the relationship between those perceptions and their teaching practices. We use a conceptual framework of educators' perceptions, teaching practices, and student engagement to analyze faculty's perceptions of their students that may inform and influence their teaching practices. This framework may also allow us to uncover potentially unknown and unintended perceptions, practices, and structures that may implicate larger social structures, such as race, ethnicity, class, gender, language, and other categories; larger social structures that may involve injustices and inequities experienced by many individuals in STEM education (Varelas et al., 2015).

Conceptual Framework

Our conceptual framework includes the notions of *educators' perceptions*, *teaching practices*, and *successful student engagement* situated in larger educational contexts (see Figure 1). The "educational interface," consisting of educator perceptions, teaching practices, and student engagement, occurs and is shaped by complex social systems (Kahu & Nelson, 2018). Students and educators experience and interact with factors that influence their engagement and success in the educational interface, including a belief in their capacity to perform a given task, their appraisal of their situation as affording or constraining their engagement, and their positive interpersonal interactions with others or the institution. In the educational interface, educators can interact with other individuals and organizations, institutional structures (i.e., policies, curriculum, disciplinary structures), and cultures that can influence their perceptions and teaching practices (Kahu & Nelson, 2018). Teaching and learning environments are such complex systems that educators and students interacting within them may be somewhat blind to all of the influencing structures and practices impacting their perceptions and actions (Varelas et al., 2015).

Figure 1

Conceptual Framework of Educators' Perceptions, Teaching Practices, and Student Engagement



Note. Educational interface and student engagement were interpreted from Kahu (2013) and Kahu & Nelson (2018).

We conceptualize student engagement as three components: *behavior*, *cognition*, and *affect*, central to student success and achievement (Kahu, 2013). Behavioral engagement includes students' outward actions, such as time spent, the effort put forth, participation in activities, and interactions with others. These behaviors can be observed or assumed by educators. For example, doing homework is a behavior that is not always observed but assumed when students produce a result. Cognitive engagement entails students' engagement in learning, acquiring knowledge, problem-solving, and reflections on their learning. For example, a student may be perceived as cognitively engaged if they apply learning to a new problem or situation. Affective engagement is a student's emotional state concerning education- or learning-related activities, such as "enthusiasm" or "interest" in a particular topic. For example, a student may demonstrate affective engagement by expressing excitement at learning new information. As opposed to cognition and affect, students' behavioral engagement may be directly perceivable by others present in the moment. Student behaviors may also be indicative of students' cognitive and affective engagement. Importantly though, any student behavior or indication of cognition or affect can be misinterpreted by others, such as faculty.

Educators' perceptions about teaching and learning, influenced by backgrounds, experiences, and beliefs, play a mediating role in processing information and can serve as mental schemas for constructing and evaluating teaching practices (Jones & Carter, 2007). Educators' perceptions of students' actions and their teaching practices result from beliefs about how students learn and behave (Pajares, 1992). Institutional structures (e.g., disciplines, curriculum, cultural norms, and procedures) influence and reflect faculty perceptions and actions, which impact students (Austin, 2011; Kuh et al., 2008). By association, faculty occupies a unique and powerful space and comprises a large portion of the relationships that students have as part of their lived experiences in educational environments (Austin, 2011). As such, an analysis of faculty perceptions of their students (i.e., student engagement) and how faculty perceive instructional practices as supporting student success can uncover the complex dynamics of teaching and learning environments (Kahu &

Nelson, 2018). We use this conceptual framework per its promise in focusing attention on faculty perceptions of successful students' characteristics and the teaching practices they enact that cultivate and support those students' success, all within a larger context.

Methods

Research Questions

The following questions guide our research:

1. How do STEM faculty conceptualize successful students in their disciplines?
2. What instructional strategies do STEM faculty claim to use that they think are effective in cultivating student success in their courses?

Study Context

This qualitative study focuses on STEM faculty from one large university in the United States classified by the Carnegie Classification of Institutions of Higher Education (n.d.) as a *doctoral university with the highest research activity*. Participants were engaged in a comprehensive (campus-wide) STEM education improvement initiative funded by the National Science Foundation, intended to foster evidence-based instructional improvements in large-enrollment, lower-division STEM courses by leveraging the distributed expertise of faculty within and across disciplinary departments. A project research goal was to investigate changing faculty perceptions of teaching and their teaching-related practices in light of the initiative activities. This paper details findings from interview data collected in 2017 around various teaching-related phenomena and perceptions.

Participant Sample

Table 1 shows disciplines, participant pseudonyms, and professional positions for the 19 STEM faculty who participated in this study. Faculty disciplines included physics, biology, chemistry, mathematics, and engineering (chemical, biological, environmental, and mechanical engineering). Nine of the faculty were in tenure-track faculty positions (assistant, associate, and full professor), and ten were in fixed-term faculty positions (instructor and senior instructor). Participants had taught at least one lower-division STEM course in the previous year and were involved in the campus initiative. Race/ethnicity and gender data were not collected in this study, and we do not want to make assumptions about participants' identities. We were further concerned with ensuring anonymity given the sample size, identification of disciplines, and professional positions of a group of faculty from just one university. We use pseudonyms that we perceive as gender-neutral. Potential interviewees were contacted by email to participate in an interview. Nineteen out of twenty-one faculty invitees consented to interviews (90% response rate).

Table 1

List of Disciplines, Participants' Pseudonyms, and Participants' Professional Positions

Discipline	**Participant**	**Professional Position**
Physics	Robin	Fixed-Term Faculty
	Jamie	Tenure-Track Faculty
Chemistry	Jordan	Fixed-Term Faculty
	Alex	Fixed-Term Faculty
	Sidney	Fixed-Term Faculty
	Casey	Fixed-Term Faculty
	Tracy	Tenure-Track Faculty
Biology	Jodi	Fixed-Term Faculty
	Peyton	Fixed-Term Faculty
Mathematics	Leslie	Tenure-Track Faculty
	Jackson	Fixed-Term Faculty
	Madison	Fixed-Term Faculty
	Kelly	Fixed-Term Faculty
	Drew	Tenure-Track Faculty
	Shannon	Tenure-Track Faculty
Engineering	Lee	Tenure-Track Faculty
	Bailey	Tenure-Track Faculty
	Logan	Tenure-Track Faculty
	Lynn	Tenure-Track Faculty

Note. N = 19. Tenure-Track Faculty include assistant, associate, & full professors, Fixed-Term Faculty include instructors & senior instructors.

Data Collection and Analysis

An external project evaluator conducted semi-structured interviews approximately one hour in length. While participants commented on a wide array of issues concerning their involvement in the education improvement initiative (see Appendix A for interview protocol), this study focuses on three questions.

1. Describe the characteristics of a successful student in your courses.
2. What kind of instructional strategies do you use that you think are most effective in developing and cultivating successful students?

3. How often do you employ these strategies in your classes?

Interviews were transcribed verbatim and transferred to Dedoose coding software for qualitative analysis. The first author created inductive codes from a first read of the verbatim transcripts, drawing perspectives from interviewees' own words in response to interview questions (Auerbach & Silverstein, 2003). During this first stage, the analyst noted an emerging pattern related to faculty perceptions of student engagement. A second, deductive round of analysis by the first author followed the inductive stage, during which we grouped faculty notions of successful students with Kahu's (2013) concept framework of student engagement. We attempted to stay grounded in faculty descriptions and matching those with definitions of the concepts. During both rounds of coding and analysis, the first analyst created theoretical memos (Montgomery & Bailey, 2007) to provide a record of developing ideas and interconnections.

We used several methods put forth by Creswell (2014, pp. 201–202) to address our findings' trustworthiness. One method we used to ensure the trustworthiness of the analysis was *peer debriefing*. The other authors supported the codes' development and participated in debriefing and data analysis sessions with the first author throughout the data's coding and analysis. The second author also reviewed 20% of the coding to increase reliability and consistency and provide ongoing contributions to the emerging codebook. (See Appendix B for codes.) In both phases, the authors discussed emerging concepts and themes based on their critical reflections on the data, and an ongoing discussion of codes and interpretations addressed (dis)agreements within the data (Auerbach & Silverstein, 2003). At least two interviewees made all the claims we report in this paper. Whenever possible, we included exact numbers of participants in conveying claims. In other instances, we use the following descriptors to provide a range of our findings' prevalence: *a few* means the claim applies to 1-5 participants; *several* means 6-10 participants; *a majority* means 11-15 participants; and *most* means 16-19.

Limitations

We acknowledge the multiple limitations of our research. First, we did not collect observations of faculty practices or student perceptions of their teaching and learning experiences. As such, our data tells a version of STEM faculty perspectives of successful students and their perceptions of instructional strategies that support those students. Nevertheless, we contend our study may still enlighten the field on how faculty descriptions and perceptions may influence interactions with students and instructional practices, particularly the observable and unobservable barriers that underrepresented students may face. Another limitation we acknowledge is that faculty who agreed to be interviewed may not represent most faculty in STEM disciplines. We realize the potential that our findings are representative of those faculty who were most engaged in making improvements via some affiliation with a campus-based improvement initiative and may not fully reflect the larger population of STEM faculty. We also do not explore, per limited sample size, faculty members' perspectives by disciplines. We also acknowledge that disciplinary norms and practices, which we did not investigate, may influence faculty practices and perspectives. Additionally, our research is based on a small sample size, with some claimed voices by a few and, in some cases, two participants. Furthermore, our study took place at one institution with one improvement initiative targeting select STEM disciplines. Our study was exploratory and, as such, does not merit generalizable findings.

Findings

Faculty Conceptions of Successful Students

Faculty conceptualize a range of characteristics that describe successful students in their disciplines, including students' ability to "make progress." Students who were making progress in a course, even if they were not earning an A grade, were considered successful. Faculty also described successful students as engaged students, namely via (a) behavior that occurred within and outside course-related activities, (b) cognition that allowed them acquiring of knowledge, performance in problem-solving, and reflection, and (c) affective means, as enthusiasm, interest, and motivation toward the discipline.

Making Progress With New Understandings Is Key Indicator of Successful Students

Several faculty (6) described successful students as those students who were "making progress" in their courses, which was considered an important indicator of success on par, but not necessarily correlated, with students' grades. Most faculty did not mention grades when talking about making progress as a characteristic of a successful student. Although some faculty equated students earning an "A" grade with their success, they also described successful students as those earning at least a passing grade, which indicated they had learned course content and made progress concerning new knowledge or skills. One faculty described successful students as those who earned an A because the material was familiar and easy for them, compared to other successful students who passed after struggling with the course. Robin (physics) described students in this way:

> *So success varies. It's totally variable. For many of these successful students, the success was that they passed the course, and they were absolutely thrilled, and that might have been a harder challenge and a larger success than the honors kid who got an A because he already knew it and it was already pretty easy.*

Another faculty chuckled as they described a successful student as those who earn an A before describing how learning the content is most important and indicates student success. Jodi (biology) described it in this way:

> *The one that gets the A of course. [CHUCKLE] What I wanted to say is the one that gets it. I feel like there are students who don't get to the point where they're going to get an A in my class, but they're still successful students in that they start to see that what we're doing in the class is not about them getting an A, but it's actually about them learning how to do biology and what biology looks like.*

Another faculty was hesitant to say grades are an indicator of student success, recognizing that students come from different backgrounds and progress at different rates depending on their larger circumstances. Lynn (engineering) said:

> *I hesitate to put a GPA [grade point average] on a successful student because that's really difficult. Every student has a different background. I won't put a number on it, but I will say a student that is progressing at the rate that they almost should be [is successful].*

Another faculty described students making progress as measured by attaining a degree and, ultimately, a productive discipline-based career. Alex (chemistry) holistically described successful students as:

> *I'd like to describe that [successful] student in the "four-year answer," and that is a successful student in general chemistry will be a student that is making progress towards a degree for four years and then demonstrates the ability to be productive in a career.*

Successful Students as Engaged Students

A majority of faculty (11) directly used some form of the word "engage" to describe characteristics of successful students. For instance, Jordan (chemistry) said, "*Frequently, my successful students are engaged.*" Sidney (chemistry) claimed, "*One thing is the student has to be willing to engage.*" Peyton (biology) said, "*Successful students are engaged; they show up to class mentally, physically...they're engaged, they're totally engaged.*" Jackson (mathematics) noted, "*Someone who is engaged with learning the material.*" Finally, Drew (mathematics) said, "*I think the two main words I would use are engagement and persistence.*"

We grouped claims around student engagement across Kahu's (2013) behavioral, cognitive, and affective domains. Although we find it useful for our later discussion, we also note that this categorization should not convey strict boundaries as faculty. Faculty frequently suggested that successful students were engaged in more than one of these areas.

Student Behavior

Behavior in the Classroom.

A majority of faculty (14) described multiple kinds of behavior as suggestive of engaged students and, thus, successful students. These behaviors included time spent on, the effort put forth on, and participation in course activities, and interactions with others. For some, this indicated students' persistence, often in light of some challenge to learn the material. In this excerpt, Kelly (mathematics) described students who persevered through difficulties and possessed the self-confidence and determination to complete the task, even though it might be difficult and take extra time.

> *The qualities that I consider for a successful student is, I think the top one is persistence. The fact that they won't give up when things get difficult is key, and the other is self confidence that they can do whatever task they're given and it might take work, and you might have to struggle for a while, you might have to step away for a day and come back and take a fresh look at the problem.*

Some faculty described more specific observable student behavior, like attending class, doing homework, and coming to their office hours. Madison (mathematics) said, "*I think the first and foremost thing is attendance and doing the homework.*" Tracy (chemistry) offered, "*Students who come to class and participate.*" For instance, Jackson (mathematics) said:

> *Someone who seeks help when they need it and goes to either my office hours, or we have a math learning center, or visits the teaching assistant's office hours and takes advantage of the resources, would be another characteristic [of a successful student].*

Behavior Outside Course-Related Tasks.

Several faculty (6) also spoke of successful students exhibiting behaviors outside of students' regular course-related tasks. Faculty viewed students as successful if they could "handle" school and be engaged in outside activities simultaneously. Lynn (engineering) said that student resumés showing extracurricular activities signaled, to them, students who can "handle" both school and other activities, connoting their greater potential for success, generally. Lynn said:

> *I always say if you have two identical resumés and one has club activity and outreach, and the other one doesn't, you're always going to go for the one*

> *with the club activity and outreach because it just shows that they can handle these things together as they've gone through the four years or however many years of college.*

These faculty perceived this balance enhanced students' overall well-being and reduced stress and, ultimately, promoted more academic success. Jordan (chemistry) felt successful students had a history of participating in other campus activities.

> *Successful students are frequently engaged across the campus as well, so it's not just in my course, I find kind of a history of them being engaged in clubs and sports or something of that effect.*

Alex (chemistry) described how successful students make social connections, which may increase their university-based success and success later in life.

> *[speaking as a student] "I'm going to balance my lifestyle for academics and social and I'm going to meet people and it's going to be an experience." And in some amount of time, which many of course hope that it's four years, sometimes it's five or six, that they will leave here with such an increase in their value that they will go and pursue a career which will ultimately get them the rewards of life.*

In contrast, two faculty perceived successful students were "the lucky ones" not to be burdened by outside stressors like jobs or family responsibilities, as related behaviors could restrict a student's ability to engage with educational activities and work. One of the faculty, Peyton (biology), said:

> *I would also say the longer I teach the more I realize my successful students are the ones that are unencumbered by other life stresses for the most part. So they're the lucky ones, the ones who don't work a ton or who have stable home lives who don't worry about things like that.*

Student Cognition

A majority of faculty (13) perceived students' cognitive engagement as indicative of successful students. Cognitive engagement denotes students' actively trying to learn, acquire knowledge, problem-solve, and reflect on their learning. We have separated cognitive engagement into separate categories for emphasis, but faculty perceived these characteristics as interconnected. For example, Alex, a chemistry faculty member, described the pleasure successful students feel when they learn something new and connect that learning to science. This faculty also perceives the affective, emotional engagement connected to the cognitive engagement. They stated:

> *... an effective student is to joyfully learn and make connections, … it's about them [students] learning how to do science and what science looks like … actually trying to understand the concepts rather than just memorize certain problems.*

Learning and Acquiring Knowledge.

Several faculty (6) described successful students as those actively trying to learn and acquire knowledge. For example, Jodi (biology) talked about an introductory biology course in which successful students do more than just memorize or learn the vocabulary. A successful student begins to learn how to "do biology" and how to be successful at learning science. They said it in this way:

> *So it's an introductory course, and there is an element of memorization and learning vocabulary that has to go into an introductory course, but really what I'm trying to get my students to see and understand is how you do biology, what types of biology are out there, and how you can be successful at learning in a field that is like biology.*

Jackson (mathematics) said, "*Someone who is engaged with learning the material and I think the best word might be present and actually trying to understand the concepts rather than just memorize certain problems.*" Jamie (physics) said successful students look over their learning assessments and work to learn what they do not seem to be understanding. They said, "*A successful student in my courses evaluates exams and looks over them to find out what they got wrong, figures out how to get to the right* *answer prior to the end of the term.*" Casey (chemistry) said that successful students "*apply what they've learned in a novel situation."*

Problem-Solving.

A few faculty (5) described successful students as those who could effectively solve problems. One faculty described how successful students in his courses could move beyond memorizing the content, applying it to different scenarios. Robin (physics) said:

> *Every class pretty much until this point is we go through a whole bunch of content, we say you need to learn this content, maybe you have to do some synthesis where you're connecting content, but it can largely be done at a rote memorization level with open notes. So you've got all the equations, you've got all the theories in front of you, but you're never going to see a particular problem that you practiced on the exam, because I'm actually asking you to take and apply this abstract set of principles and ideas and mathematical reasoning and physical reasoning, conceptual reasoning, all to a different problem.*

In this excerpt, Leslie (mathematics) described successful mathematics students as utilizing problem-solving skills to help them solve challenging problems.

Successful students are capable of doing mathematics, just because they don't see a solution path right away or the answer right away, that doesn't mean they're not capable of doing mathematics...So building some really good thinking and reasoning skills that can help them solve problems in multiple contexts.

Reflective around Learning.

A few faculty (3) described successful students as those who reflected on what they were learning and their actual learning processes, sometimes interacting with others. In one example, Jamie (physics) said that successful physics students talk with each other about their understanding of the concepts. They said, "*I think understanding the physics also requires that they discuss with each other their interpretation of what's going on there.*" Jodi (biology) described successful students as those that reflect on how they learn. They said, "*There's more of this sort of competency, and then there's also this meta cognitive piece about how do I [student] learn biology and why is it important to me."*

Another faculty spoke of successful students as those who were able to critically review themselves to practice the skill of self-reflection and learn how to see their own mistakes and be able to avoid them. They have students talk to one another as another way to reflect on their learning. However, they also describe a lack of reflective learning as a characteristic of unsuccessful students they perceived as unable to engage in learning effectively. They describe unsuccessful students as those barely educated above a middle school level, and, as such, they were unable to engage in reflective learning. They also perceived college entry standards as inadequate in keeping underprepared students out of their classroom. Jordan (chemistry) talked about what they did:

> *What I do is encourage the students to critically review me. And when they critically review me, I use that as a doorway to get them to think about whether or not they have made similar mistakes and how they can avoid those mistakes and I get them to talk about that or engage in some sort of an evaluation of their mathematics...My average student is just barely literate enough to participate in a critical review of something written above an eighth grade level, and I don't see it getting a whole lot better in the near future because the entry standards for the school are a challenge.*

Student Affect

A few faculty (5) described successful students as those demonstrating student affect or certain emotional states around new material and experiences, indicative of their engagement, and thus, success.

Enthusiasm and Interest.

A few faculty described successful students as enthusiastic and interested in the subject and material. Logan (engineering) described successful students as being excited about course material and its possible application:

> *I feel like I've had a lot of them, and they're folks that really are pumped up about the material, like they had no idea this was so cool and how it relates to everything.*

Jodi (biology) detailed a successful student as someone who is enthusiastic about learning the material, which can translate to a deeper understanding of related careers:

> *... feeling like, wow, I figured out how to learn biology, and I learned a ton, and I could walk out of here and feel like I know what a biologist is doing.*

Motivation.

Two faculty portrayed successful students as those who were self-motivated. In this excerpt, Tracy (chemistry) described successful students feeling agency and efficacy in course activities, generally doing the work needed to understand course content. Tracy described students in this way:

> *… being self motivated or self sufficient in being able to read material presented in the text or in publications and come to us with questions if they had them or do the exercises to be sure they were getting the material and understanding it.*

Lee (engineering) described successful students as those intrinsically motivated to the degree that a faculty member's role can be more of a facilitator of student learning, allowing students to take more ownership of it.

> *[students] get to a point where they're intrinsically motivated to learn and you are really kind of facilitating their learning…[students think] hey, I'd really like to learn more about this thing. For me a successful student is someone who's taken ownership of their learning and they're not in the mode of, it's your job to give me everything that I need to learn this material.*

Instructional Strategies Faculty Used to Help Students be Successful in Their Courses

Faculty spoke of a wide range of instructional strategies they described as effective in developing and cultivating student success—faculty detailed lecturing strategies as well as specific evidence-based instructional practices (EBIPs). Faculty often spoke of instructional strategies as fostering student engagement in some way. A few faculty discussed instructional strategies promoting student success in light of their perceptions of differing levels of students' potential for engagement.

The Use of Lecture-based Instructional Strategies

More than half of the faculty (10) interviewed mentioned using lecturing as an instructional strategy within their courses when asked about fostering student success even if they recognized some limitations. The term lecturing refers to teaching where faculty deliver instruction or content primarily through talking, frequently while positioned in front of the classroom.

Some faculty spoke of trying to minimize their presence in the classroom to cultivate more student success, even if they felt some lecturing by them to be necessary. Leslie, a mathematics instructor described how they decentralized themselves as the mathematics expert or authority, but they still talked about also needing to cover the content that students needed. They said, "*I really try to decentralize myself as the mathematical authority in the room…[but] I feel like I have to make sure I get through all the content.*"

Tracy (chemistry) also described how they were trying to minimize their lecturing time overall to cultivate student success. Although they felt lecturing was an integral part of their teaching practices, they admitted that it did not always foster students' success or engagement.

> *I really move to try to avoid standing up there and lecturing for extended times, which I don't think supports all of those things [characteristics of successful students] or even many of them. But inevitably there is some lecture.*

None of the faculty who discussed lecturing claimed it as their only means of conveying content to students. To improve student success, faculty used other types of lecture-based instructional strategies to engage students through questioning strategies or providing periodic opportunities for students to work on problems.

In this excerpt, Jackson (mathematics) detailed how they tried to engage students directly in the conversation during lecturing to foster student success. They tried to get students involved by asking questions and waiting for someone to respond to create a discussion. They described how just delivering information was not as effective as engaging students. They stated it this way:

> *I try to make my lectures interactive so that the students are involved, and often I'll ask questions and wait for someone to answer the question and try to create more discussion around the ideas, rather than just me conveying information without engaging the students directly.*

Similarly, Jamie (physics) claimed they lectured and talked too much during class times when asked how they cultivated student success. They described how they attempted to minimize it via several opportunities for students to engage with content through other means. They said:

> *In lecture, I'm still talking too much, but there's about five or six opportunities where the students work for three minutes or so on getting solutions to a problem.*

The Use of Evidence-Based Instructional Practices (EBIPs)

Eight faculty specifically described different kinds of EBIPs in their course design and activities they planned to cultivate student success. They explained how these practices would develop and foster successful students by helping them to stay focused on and learn the content more effectively. These practices included specific course designs and actual student activities.

Course Design and Student Activities

Several faculty talked about designing their courses to foster student success by using specific EBIPs that support and cultivate students' success in their courses. One faculty described how they designed their class so that students would know precisely what they needed to do and would be less likely to fall behind. They describe their instructional approach as highly structured around the content and learning outcomes, with student activities and assessments directly aligned with them.

They contrasted their course design as very different from a traditional class that involved lectures and taking exams. Jodi (biology) described it in this way:

> *I design my classes in what I call a highly structured class and so we try to structure it in such a way that they can't get behind. So by highly structured I mean they are given content every week. It's not like here, come to lecture and then take this exam and then you're done. Then we also use a really heavy backwards design in all the things we do with that where we have learning outcomes that we want them to be able to do and everything we do is aligned to those learning outcomes, and then we tell them all of that.*

Another faculty described using a flipped classroom design in which students engaged with the learning materials around a topic outside of class before experiencing instruction on the topic in class. They discussed how students needed practice in applying what they have learned to new situations, and it was essential to have students practice in class so they could see it as an important goal. Casey (chemistry) described their instructional strategies in this way:

> *So like the flipped classroom, they're always working on problems while they're in class. There is virtually no standard lecture that goes on.*

One faculty talked about using case studies to provide students with realistic situations in their engineering courses. Lee (engineering) described how they scaffolded their instruction to provide supportive activities that moved students toward a more robust understanding that did not overwhelm them.

> *So for me I think strategies I've used are case studies, kind of guided design in one of my classes where I have tried to make a realistic scenario, but have it scaffolded enough that it doesn't seem totally overwhelming to students.*

Group Work

Several faculty (5) described group work as an effective strategy for helping students be successful. One faculty (Jamie, physics) described implementing class sessions where students worked in groups of three on specific tasks and then presented their work.

> *So they work in groups of three, round tables, groups of three, they have certain tasks, they sit down and work together for fifty minutes, and one of the groups presents their findings, they discuss it, and we go onto the next thing.*

Another faculty talked about using groups as a strategy for cultivating student success that builds interdependence among the students to hold each other accountable for attending class and supporting one another in their group and the course. Peyton (biology) described it as, "*Trying to develop good group contracts with them, so they feel like they have to be there for each other."*

One mathematics faculty, Jackson, described a strategy they used to foster student success. They put students in groups to take quizzes they determined were particularly difficult. Specifically, they wanted students to work together to solve problems. Through this strategy, they talked about how students were engaging with the content and with each other. Jackson described this strategy in this way:

> *So every couple of weeks without announcement, there will be a quiz, and the quiz will focus on sort of generally more difficult concepts than you would have on a normal exam, but they get to work together, so usually, they're able to figure it out as a class. We give them about fifteen or twenty minutes per quiz to come up with the answers, and that to me fosters engagement, engaging with the material and with each other, and trying to help each other understand the concepts.*

Instructional Strategies that Encouraged Student Cognitive Engagement

A majority of faculty (12) described instructional strategies that cultivated student success and that were closely tied to fostering students' cognitive engagement, which included activating prior knowledge, connecting prior knowledge to new knowledge, applying their learning to new problems, and engaging students in discipline-related methodologies.

The faculty discussed instructional strategies that would help students activate prior knowledge to foster successful students. Peyton (biology) said this would encourage students to recognize what they do not know, the limits of their knowledge, and what they might want to learn. They said:

> *I'm trying to engage what they know already. When we start a topic, start a class period, what do we already know and where are the limits of your knowledge, and what are the things that I think you might be wondering in that sense.*

Similarly, Madison, a mathematics instructor, fostered student success by connecting new ideas to ones that students already understood. They did this to make sure that students were ready to learn and so students could make obvious connections when topics were discussed.

> *So this idea of connecting something [new learning] to the older stuff that they [students] should know serves as kind of two things. One is just to make sure everybody is up to speed on it so they can make the connections and then pointing those connections out.*

One faculty discussed encouraging student success by designing their instructional activities so that students could apply what they learned to new situations. Casey (chemistry) spoke about how some students resisted doing these kinds of activities, but they felt it was essential to have students do application problems, particularly in a class setting, and to see this as a fundamental goal of learning the discipline.

> *You have to give them [students] practice at applying what they've learned in novel situations, which is not something they like to do, but that's beside the point. You have to have those types of questions. You have to do it in class. It has to be something that they see as a goal for them.*

Jodi (biology) described an assignment they designed to foster student success. They considered it “authentic scientific practice” to help students engage in scientific thinking and processes such as asking questions, making a hypothesis, collecting data, and writing results that culminate in a scientific-style paper. Jodi also asked them to self-assess and peer assess to practice what scientists actually do.

> *We wrap all that [class activities] into what I consider to be the authentic scientific practice, where at some point they get to ask a question and make a hypothesis and collect some data and write a results and a discussion and end up with kind of a scientific style paper, but then I ask them to self-assess and peer assess and do sort of the processes that we as scientists do.*

Instructional Strategies that Encouraged Students' Behavioral Engagement

Faculty detailed instructional strategies that would encourage student behavior to lead to more success. For example, faculty talked about using backward design, flipped classrooms, and group work in labs and studios to encourage successful behaviors (see above section for relevant quotes). Along with these strategies, several faculty (9) also described how they designed their instructional strategies to foster student success by encouraging them to talk with each other and their instructors. Robin (physics) described how all of their assignments were designed to be difficult enough to force students to talk with other students or seek help from their instructors to cultivate student success.

> *So I would say the one thing that is sort of a common thread through all of the instructional design that I've done is how do I get people talking. How do I get them talking about physics because if you're talking, you're learning, and so every single thing from lab to recitation to homework, even the challenge homework is designed to be hard enough that most of them will have to seek out help from other students, will have to go online to the support group, will have to go to the "worm hole" which is where the T.A.'s hold office hours.*

Leslie (mathematics) described how they tried not to answer students' questions directly and, instead, encouraged them to talk with their peers as a way to develop successful behavior in students. They described how they had students talk to someone sitting next to them about the problem.

> *So not answering their [students] questions directly. Getting them to talk to peers, if I pose a question to a class and it's just silence in the room, I'll have them talk to somebody next to them for a couple of minutes to talk about the problem.*

Jackson (mathematics) talked about how there might be awkward silences when they asked students questions, and students did not respond. They described how engaging with the instructor, even when students were reluctant, was important for their success. They said, "*I try to get them [students] to respond to me and engage with me, even if that takes some awkward silence periods where I'm waiting for someone to respond."*

Instructional Strategies that Encouraged Student Affective Engagement

A few faculty (5) discussed instructional strategies that encouraged students' affective engagement and thus cultivated student success. They described efforts designed to build students' self-esteem, connect with students through empathy and humor, and encourage students' interest in the content by showing it more relevant in contexts meaningful to students. Kelly (mathematics) tried to influence student success by telling students they could be successful. They talked about being their students' advocates and telling them they were amazing and capable of success. They described trying to build up their self-esteem. They said:

> *I'm a very big advocate of constantly telling my students that they're awesome and amazing and telling them that they can do this and really building up their self-esteem and building up that yes, I agree this feels hard, but you can do this.*

Logan (engineering) used storytelling and humor to connect with students and felt this fostered their success. They described having a great deal of empathy for their students, and they tried to convey that feeling to students through stories and laughter. They said:

> *I tell lots of stories constantly, tell stories. I make folks laugh, and the stories are all related to what's going on … I connect with them [students], make them laugh, I really have a great capacity I feel like for empathy. I have a great capacity to kind of appreciate where they're at.*

Peyton (biology) described how they tried to find something that students would be interested in, and that was unique and relevant to the students to foster success. They discussed how they tried to find something that would be of interest or a unique and relevant topic to students, so they saw a purpose. They described it in this way:

> *I'll try to find something that might peak their interest, something that's unique to humans or that's clinically relevant in some way, or something like that, so it could feel purposeful that they know that information.*

Instructional Strategies in Response to Differing Levels of Student Competency

A few faculty (3) described different types of instructional strategies they thought would cultivate student success that was tied to the different levels of student competency. A few faculty perceived student engagement levels to be different in their lower division versus upper-division classes, which inspired them to use different instructional strategies that they described to help secure each group's success. Drew (mathematics) spoke of using more interactive strategies in their upper-division courses to ensure student success but trimmed them in their lower-division courses. They described limited lecture-based instruction in their upper-division classes, and students engaged collaboratively in problem-solving activities. In contrast, Drew described "quite a bit" of lecturing in their lower-division courses. They described it in this way:

> *I have taught some [upper division] classes where I've done almost completely without lecture and just given students a series of problems to work on collaboratively, and I shy away from being the dispenser of the authoritative answer. When I'm teaching lower-division courses, there's still a fair amount of me talking...or quite a bit of lecture goes on in the lecture part of the course.*

Jordan (chemistry) described students in their lower-division courses to have limited literacy and numeracy skills, which was not conducive to success. In contrast, students in upper-division courses have skills advanced enough to engage in more analysis and conversation around the material, leading to more success. They described their average student as lacking literacy and numeracy skills. The ability to critically review the work was considered an important skill to develop as a successful student. They described it in this way:

> *In [name of lower division course], my average student is just barely literate enough to participate in a critical review of something written above an eighth-grade level. And that's scary to me. Numeracy is comparable. So, in [name of upper division course], they're college numerate, they're college literate. You can have a conversation with them about these things, and they can critically review the work, and they understand what's going on to a degree where they can critically review themselves substantially better.*

Discussion

In this paper, we reported an exploratory study of STEM faculty notions of successful students and the instructional practices they employ to cultivate student success. We found faculty perceive a range of characteristics and factors indicative and predictive of student success. Faculty considered successful students to be those who were “making progress,” even if they were not earning high marks in their courses. Faculty described progress as learning course content and gaining new knowledge and skills. Beyond this, faculty broadly described successful students as “engaged” students, which we could group across three domains: behavioral, cognitive, and affective (Kahu, 2013). A majority of faculty perceived multiple behaviors (those directly observable by faculty and those not) as essential characteristics of successful students. Behaviors included time spent and the effort put forth on coursework, participation in course activities (those in the classroom and those across campus), and interactions with other students and instructors. Similarly, a majority of faculty described students’ cognitive engagement as indicative of their success. Students’ cognitive engagement included acquiring new knowledge, problem-solving, and reflective learning. To a lesser extent, faculty perceived students’ affective engagement equated with their success, including students’ enthusiasm for and interest in the discipline and their motivation to learn.

Faculty described a wide range of instructional strategies they perceived as effective in developing and cultivating student success. Faculty described lecturing strategies as well as practices known among researchers as evidence-based instructional practices (EBIPs). Although more than half of the faculty described lecturing in their courses, they also detailed minimizing the length of time they spent lecturing, using more questioning techniques, and group work to make their classes more interactive and supportive of student success in allowing students to be more engaged. Faculty detailed numerous types and uses of EBIPs to cultivate student success, including around course design and other instructional strategies. Faculty described using backward design, flipped classrooms, case studies, and group work as strategies to cultivate student success. Faculty also detailed how they differed their instructional strategies based on their perceptions of the potential level of student engagement across students in their courses, describing using less obviously engaging techniques in lower-division versus upper-division courses.

A majority of faculty discussed implementing instructional strategies they thought would engage students' cognition, prime them for, or solidify learning something new, such as activating prior knowledge, connecting it to the new knowledge, applying knowledge to new situations, and engaging students in discipline-related practices. A majority of faculty also discussed implementing instructional strategies they thought would cultivate students' behavioral engagement, like fostering students' interactions with other students and faculty. Finally, some faculty detailed instructional strategies they thought could impact students' affect to increase their self-esteem and interest in the subject and material. To accomplish this, the faculty used empathy, humor, and statements affirming students' abilities.

In general, faculty saw student engagement as essential to learning and success. While the importance of student engagement to their success is surely evident to many readers of this paper, we contend that this is still a meaningful finding. Researchers have recently documented that STEM faculty largely engage in lecturing, favor and justify it over the use of EBIPs, and are sometimes unaware that EBIPs can improve their courses, often via student engagement (Bathgate et al., 2019; Freeman et al., 2014). Our findings contradict the perception that STEM faculty are homogeneous in their practices and commitments, largely unaware of EBIPs, or resistant to use them in their courses (e.g., Bathgate et al., 2019; Patrick et al., 2016). We found otherwise and confirmed that STEM faculty, even at a research university, break some assumptions around their teaching-related weaknesses and strengths (Bouwma-Gearhart, 2012). The fact that the STEM faculty in this study also knew about and tried to implement EBIPs that research confirms helps facilitate student engagement is encouraging, including those hoping to improve experiences among underrepresented student groups in STEM (Haak et al., 2011).

Indeed, many faculty seemed to recognize the limitation and impact of solely lecture-based instruction on students and attempted to include EBIPs (e.g., interactive questions, small group work, discussions) throughout their instruction. Their claims of implementing EBIPs matched Hora’s (2015) detailed observations of STEM faculty teaching practices and his caution that wide-held assumptions and conceptions around faculty lecturing are narrow and inaccurate and discounting of faculty practice that incorporates student-engaging practices within and alongside lecturing. To a biased or untrained observer, a faculty member may appear to be “only lecturing” even as they engage students with meaningful questioning strategies or have students work through a problem at their seats during a brief pause in their talking. These strategies surely enhance student success. This said, we do not know the realizations of our faculty participants’ claims as actual faculty practice, and we heed some caution against assuming faculty claims about their teaching practices are consistently accurate (Ebert-May et al., 2011). Still, much of what we heard from faculty indicated a commitment to engaging students in multiple ways and understanding practices to elicit this, all of which indicate faculty schemas and dispositions to build upon by those who want to help faculty realize improvements in their teaching. We echo others in asserting that uncovering these realities are instrumental in designing and implementing initiatives meant to help faculty change practice, to meet faculty where they are at, and to consider faculty partners in improving postsecondary STEM education in their courses and those of their colleagues (Bouwma-Gearhart & Ivanovitch et al., 2018; Bouwma-Gearhart & Lenz et al., 2018).

We note some possibilities for attention for these initiatives from our research as well. Our recommendations build on those of other researchers that have demonstrated that educational interfaces are comprised of norms and expectations that are often implicit (Orón Semper & Blasco, 2018). Educators' implicit expectations, specifically embedded in various activities and structures, such as syllabi and other course materials and discussions with students, stand in contrast with their more obvious indications (Orón Semper & Blasco, 2018). Simply put, faculty may not express their implicit expectations and related assumptions. In our study, some faculty indicated students to be successful even when not earning an A grade, potentially not evident to students whose experiences in other educational settings might have convinced them of otherwise. This may lead some students not to know that they are achieving meaningful success (e.g., the student earning a C, or even B, in a course), which may, in turn, discourage their future success in that course or, even, in the program or discipline.

Equally, if not more, concerning is that ambiguity of faculty expectations may also impact students' positioning themselves to be successful. Some faculty expectations and perceptions around student behaviors, such as students taking advantage of office hours, raising hands, and asking questions during class, that remain implicit may beget unexpected (and unintentional, on the part of faculty) negative consequences for students (e.g., Shapiro & Sax, 2011; Orón Semper & Blasco, 2018). Faculty also interpreted students' affective engagement (i.e., interest and enthusiasm) around a subject as indicative of their success. Actions that are often nonverbal in nature (e.g., facial expressions or verbal responses) can depend on the students' comfort levels and personal preferences with expressing those emotions. Several faculty spoke about how they would talk to students and engage in conversations that provided them with feedback about their progress or understanding. However, many of these interactions were informal and may not have involved most students, those succeeding as well as those struggling. Faculty practices and expectations may ultimately assume and encourage a particular type(s) of student, from groups traditionally successful in STEM. Not understanding the implicit or hidden expectations of faculty, women, racial/ethnic, and other underrepresented groups may not recognize, be positioned to utilize, or confident in their ability to use the resources available to them (Kahu & Nelson, 2018; Shapiro & Sax, 2011).

We call out the faculty expectations and perceptions noted above as based on, and reinforcing, inaccurate assumptions around *meritocracies*, in this case, learners' abilities reflected accurately by their progress and measurements on traditional academic indicators and metrics, such as grades (Guinier, 2015). Faculty frequently used standardized midterms and final exams as the predominant determination of grades and student success. In one case, a faculty member only shared an overview of how well the class performed on the exam in the form of a bell curve and did not share the student's individual exam performances with them. In other cases, faculty assumed that students came to college to socialize and earn a degree that would provide them with a valuable career and good life, which assumes a predominantly young student who is unencumbered by other life responsibilities. Meritocratic assumptions and resulting environments are especially problematic for historically underrepresented groups in education environments; in postsecondary STEM, these groups still primarily are those not white or male (McLaren, 2017). A system based on notions of meritocracy places the burden of achievement on the individual's shoulders. Therefore, succeeding or failing becomes the student's responsibility and assumes the student has the knowledge and understanding of the explicit and implicit expectations, norms, and practices that may be prevalent in many STEM courses. Long held cultural norms (e.g., competitive, merit-based admissions, and advancement criteria) are reinforced and may continue to signal to some students that they are not suited for STEM careers (Johnson, 2007; Rainey et al., 2019).

STEM faculty may have a difficult time seeing these biases. Overall, the educational interface is complex, with those interacting in it (including faculty and students) somewhat blind to all of the influencing structures and practices impacting their perceptions and actions (Varelas et al., 2015). And some of this may also be due to the nature of the disciplines. STEM classrooms and disciplines are often presented as neutral to race, ethnicity, and gender. Thus, responsibility for learning is centered on the student, a decisively narrow focus in discussions of improving postsecondary educational outcomes. Faculty perceptions or assumptions that student learning is the student's responsibility connotes a one-sided effort to support student success, focused on changing students' behaviors and attitudes. This perspective assumes students show up inculcated into STEM environments and fails to recognize the complexity of college classrooms and the institutional realities that exist (e.g., large lecture classrooms, competitive admissions processes, access to technology). Notably, a few faculty expressed an awareness of structures that may act as barriers for some students, such as those who described minimizing exams as the sole determinant of grades or attempting to change departmental policies around group exams.

Implications

Not recognizing the norms and expectations that come together in the postsecondary STEM education interface promotes a meritocratic model and may disadvantage students from diverse social, cultural, and economic backgrounds. Beyond perceptions already discussed above, several faculty members we spoke with also likely considered the notion of successful students in relation to the traditional, narrow view of a college student as a young adult (18-22) who goes to college for four years right out of high school, earns a degree and obtains a job associated with that degree right after graduation. For many faculty, successful students generally did not have to support themselves financially and, thus, potentially have powerful social networks or family structures. Such affordances of student success, like some noted above, are arguably outside of faculty control, further shifting responsibility for student success away from faculty, programs, and institutions.

We acknowledge the broad array of faculty perspectives regarding the characteristics of successful students and teaching strategies. We also acknowledge that perspectives that represent actual barriers and challenges to student success were difficult to detect in the data. And research surely suggests that students experience and interpret college environments differently (Whittaker & Montgomery, 2014) and may bring a range of expectations and commitments to their classes (Messineo et al., 2007). Students from underrepresented groups will not all struggle with the faculty's implicit and tacit expectations. Yet, we assert that faculty expectations that may otherwise appear neutral can influence many students' conceptions of their success and willingness to engage in ways that lead to their success.

We have greater concern for most students regarding the faculty expectations we heard of for this study and how these may be reflected in their curriculum and instructional strategies, and other teaching artifacts. For instance, faculty spoke about structuring their courses differently depending on students' perceived abilities and preparedness and in faculty's felt need to cover the content. Faculty who perceived students as lacking in academic preparedness, often those in lower-division introductory courses, were more likely to cover content through lecture-based approaches, even though they were aware of the limitation of lecturing as the most effective teaching strategy. Faculty expressed frustration with students' limited literacy and numeracy skills and lack of students' abilities to review their work critically and discussed how lower-division course students might be less engaged. We see the potential for a self-fulfilling loop here, where faculty perceive students to be less engaged, so engage them less, further guaranteeing less student engagement (and success). Some faculty may still need to consider the need to better engage all learners and strategies to do so even when they perceive that students may lack some knowledge or skills.

We believe our findings hold other implications for faculty and those working to support them. Studies of faculty adoptions of EBIPs suggest that faculty may be reluctant to try EBIPs because of a lack of experience, time, or incentives (Brownell & Tanner, 2012; Graham et al., 2013). However, research also suggests that carefully structured professional development activities that allow instructors to incorporate EBIPs show improvements in student engagement and achievement and increases in faculty use of EBIPs (Addy, 2011; Mataka et al., 2019). Faculty in our study discussed and claimed to implement various teaching practices that researchers have linked to student success, including infusing EBIPs into their lecturing. Faculty were not tied to just one teaching strategy and indicated they tried to adapt their instructional practices to meet their perceptions of what students needed, even as they faced concerns of other barriers (e.g., time constraints and content coverage). The use of various EBIPs by faculty suggests an awareness of the potential for engaging students in various ways and understanding various practices that can help students achieve success. As we have argued limitedly elsewhere, STEM faculty's understandings and practice attempts should be acknowledged, applauded, and built upon.

While faculty primarily discussed the characteristics of successful students in the context of their courses and disciplines, they also equated success with a more holistic view of students persisting beyond their classes, completing a degree, and pursuing a STEM career. These faculty perspectives suggest broader opportunities for departments to build more obvious networks and support strategies with student service personnel that broaden faculty knowledge of student supports outside the classroom. Tapping into faculty members' espoused commitment to helping their students succeed can open the door for these same faculty to explore more EBIPs, that continue to foster the kinds of characteristics that faculty actually value most in their students and are seen as critical markers of success.

Of course, faculty members operate within contexts that allow for considerable autonomy over their teaching. They also influence other faculty within their disciplines, and those that they trust and respect may be best positioned to help them notice and challenge their assumptions and perceptions, and practices that may remain tacit to students. Peers might help other faculty better acknowledge and understand that the educational interface (Kahu & Nelson, 2018) can be full of many tacit rules and norms, thus allowing those most embedded in the system (i.e., themselves) not to recognize that those newer to a system or less knowledgeable or influential within it (i.e., students and especially minorities) can be somewhat unaware of how things are done (Varelas et al., 2015). Those supporting improvements to faculty teaching can promote and support continual monitoring by faculty of the affordances and constraints that their expectations, perceptions, and related instructional structures might create around student success. Faculty engaged in improvement initiatives would benefit from reflective activities that have them investigate their perceptions of successful students and the instructional practices designed to foster student engagement, their successes, and less positive potential unintended consequences.

Conclusions and Future Directions

Using interviews from 19 STEM faculty, we sought to examine how faculty described their students, particularly those viewed as successful, and how they thought about their instructional practices that supported those students. We found faculty perceptions of successful students varied widely and found a pattern of faculty members' conflation of "successful students" with the concept of student engagement, specifically students' behavioral, cognitive, and affective actions or characteristics. The STEM faculty who were involved in this study were committed to supporting students, and they recognized that student engagement, in its various forms, was key to achieving success. The wide range of instructional strategies, many of them research-confirmed in fostering student success, indicated the faculty's motivation to support students engaging in the content. It was clear they wanted their students to learn and were concerned when students were unsuccessful. Still, we found that some faculty still claimed to continue to rely primarily on lecturing as a strategy, without obvious incorporation of EBIPS, especially in lower-division introductory courses, where research suggests the use of EBIPs is actually most effective and needed (Haak et al., 2011).

However, our dominant concern is that faculty may assume that students know how to engage effectively to be successful in STEM classes and courses. We are also concerned for faculty making assumptions about indications of student engagement, especially around behaviors that some students may not know, or feel empowered, to do. Like other humans, faculty may be unaware of their perceptions and their consequences, leading to further reification of implicit expectations and the assumptions associated with them (Pajares, 1992). Such perceptions may underlie and reinforce educators’ unspoken expectations that privilege some student groups over others. We advocate for this finding to become more understood and challenged by faculty, leaders, and professional developers. This consideration may even add to our growing understandings around the underrepresentation of women, students of color, and other groups in STEM disciplines, a notably complex problem with roots in many related phenomena.

We encourage future scholarship around faculty perceptions and practices and their impact on student success and persistence in STEM fields. Research is needed that further examines these phenomena with a more significant number and diversity of faculty, with an exploration of other contextual factors (e.g., type of institution, discipline, teaching, and teaching-related professional development history) and faculty members’ social identities (e.g., gender, race, and ethnicity). Additionally, we encourage research that explores faculty members' perceptions in light of their actual teaching practices, including their implementation of EBIPs and their impact on student engagement.

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Appendix A

Faculty Interview Questions

1. I'd like to know more about your position at [Name of University].
a. Specifically: What is your official title?
b. What classes did you teach this academic year, 2016-2017?
c. Have your teaching responsibilities changed since last interviewed for this project?
d. How much autonomy do you have over what and how you teach?
2. Do you interact regularly with any others concerning issues of teaching and learning?
a. [If yes], please provide detail regarding those interactions: including
i. who? 1. Are these people in your discipline/department/program?
ii. how often?
iii. regarding what specifically?
b. What encourages or discourages these interactions?
c. Has [Name of Initiative] influenced these interactions in any way?
3. I'd like to hear about your engagement with the [Name of Initiative] project. Specifically:
a. What has been your affiliation with the [Name of Initiative] project? What activities have you attended?
b. Have you noted any impact of [Name of Initiative] on you?
c. Have you noted any impact of [Name of Initiative] on others?
4. Please describe any evolution in your teaching practices over the last couple of years that you can attribute to improvement initiatives or professional development activities. [If not mentioned, probe for specifics via questions a and b.]
a. Have any university or departmental initiatives or teaching professional development opportunities impacted this evolution?
b. Has [Name of Initiative] influenced your evolution in any way?
5. I'd like to hear about your assessment practices while teaching.
a. To what extent do you collect data/information about student learning?
b. Are you teaching practices informed by data/information about student learning?
c. Are there means in the classes/courses that you teach for students to reflect on their own learning data? [If yes], Can you detail these processes?
6. Describe a successful student in the courses or programs in which you teach.
a. Overall, what do you consider as the most effective teaching strategies towards developing these things?
b. To what extent do you employ these teaching strategies?
7. A goal of the [Name of Initiative] project is widespread improvement to teaching practices and learning outcomes in undergraduate STEM education across [Name of University]. Our general strategy is promoting educators' learning about evidence-based instructional practices via interactions with other educators.
a. What do you think about this goal and strategy? Do you have any evidence that widespread improvement to teaching practices and learning outcomes in

undergraduate STEM education have happened in the last couple of years at [name of University]

b. Can you attribute any changes to the [Name of Initiative] project?

c. Have you noted any affordances and barriers towards widespread improvement to teaching practices and learning outcomes in undergraduate STEM education, that can inform efforts like [Name of Initiative]?

8. A specific goal of the [Name of Initiative] project was to promote active learning and cooperative learning, especially in large, introductory, gateway courses. We define active learning and cooperative learning as X [definitions provided to interview on a handout]

a. What do you think about this goal and strategy?

b. Do you have any evidence that promote active learning and cooperative learning has increased in large, introductory, gateway courses in the last couple of years at [name of University?

c. [If so] Can you attribute any changes to the [Name of Initiative] project?

d. Have you noted any affordances and barriers towards active learning and cooperative learning has increased in large, introductory, gateway courses, that can inform efforts like [Name of Initiative].

Appendix B

Codes and Descriptions

Code Names ● Childcodes	Code Descriptions
Characteristics of successful students	Any words/phrases used to describe characteristics of successful students
Student Engagement	Any mention of the word engagement or some form of the word engage when talking about students. This concept may be implied in how the faculty describes students but generally equates to behavior, cognition, and affect
● Behavior	Describes students' outward actions, such as time spent, effort put forth, participation in activities, and interactions with others Examples include raising hand in class, asking questions, going to office hours, doing homework, using resources.
● Cognition	Describes students in terms of learning, acquiring knowledge, problem solving, and reflections on their learning
● Affect	Describes students' emotional state with respect to education- or learning-related activities, such as enthusiasm, interest, or motivation in a particular topic.
Instructional Strategies	Any mentions or description of a teaching strategy
● Lecture	Any mention of lecture-based instruction
● EBIPS	Any mention of evidence-based learning practices including active learning strategies that engage students in activities
● engage behavior (11)	Instructional strategies that encouraged students to engage in behaviors related to being successful
● engage cognition (12)	Instructional strategies that encouraged

	students to engage in terms of learning acquiring knowledge, problem solving, and reflections on their learning
• engage affect (6)	Instructional strategies designed to engage in students' emotional/psychological state with respect to education- or learning-related activities, such as enthusiasm, interest, or motivation in a particular topic.

CHAPTER 4 – Manuscript Three

STEM Faculty Instructional Data-Use Practices: Informing Teaching Practice and Students' Reflection On Students' Learning

Cindy Lenhart and Jana Bouwma-Gearhart

Abstract

This paper explores the affordances and constraints of STEM faculty members' instructional data-use practices and how they engage students (or not) in reflection around their own learning data. We found faculty used a wide variety of instructional data-use practices. We also found several constraints that influenced their instructional data-use practices, including perceived lack of time, standardized curriculum and assessments predetermined in scope and sequence, and a perceived lack of confidence and competence in their instructional data-use practices. Novel findings include faculty descriptions of instructional technology that afforded them access to immediate and nuanced instructional data. However, faculty described limited use of instructional data that engaged students in reflecting on their own learning data. We consider implications for faculty's instructional data-use practices on departmental and institutional policies and procedures, professional development experts, and for faculty themselves.

Introduction

Calls for Increasing Instructional Data-Use Practices in Postsecondary Education

In response to calls for increased accountability from policymakers, accreditation agencies, and other stakeholders, higher education institutions are devoting more resources to gathering and analyzing evidence around student learning outcomes to inform strategy promoting student success and persistence (Bouwma-Gearhart & Collins, 2015; Ewell & Kuh, 2010; Jenkins & Kerrigan, 2008). Specifically, educators are asked to gather and respond to evidence of student learning to inform their future teaching-related decisions and practices. These calls, including those faculty working in the STEM disciplines (science, technology, engineering, and mathematics), demonstrate a growing focus for many concerned with improvements to postsecondary education (Bouwma-Gearhart, 2021; Hora et al., 2017). This push is well-founded. Educators' systematic use of instruction-related data has been shown to enhance student learning and achievement via faculty data-driven decisions (McClenney et al., 2007).

The push for faculty to engage in systematic instructional data-use practices goes beyond their summative examination of students, often infrequent and not particularly illuminative (Bouwma-Gearhart & Collins, 2015; Hora et al., 2017), to include more formative data-use practices, including that can inform immediate teaching practices. These connote increased repertoires of practice for many faculty, placing on them additional demands and, by association, those who seek to help develop their teaching-related practices. Emerging research indicates that STEM faculty are not necessarily ready to utilize diverse instructional data effectively or to constructively inform practice generally (Hora et al., 2017). Teaching improvement interventions that target STEM faculty development of effective instructional data-use practices are becoming more numerous (Bouwma-Gearhart, 2021; Bouwma-Gearhart & Collins, 2015). However, alongside limited knowledge about how postsecondary educators make decisions about their teaching overall (Bouwma-Gearhart, Ivanovitch, et al., 2018), we still know little about how instructional data informs faculty teaching-related decisions (Bouwma-Gearhart & Hora, 2016; Hora et al., 2017). This lack of knowledge limits abilities to help faculty enhance their instructional data-use practices, meet the calls of those calling for this, and respond to faculty members' actual realities and needs.

What we do know from the research around educators' instructional data-use practices largely concerns the degree to which K-12 educators implement policies mandating these practices (Meyer & Rowan, 1977; Spillane, 2012). A growing body of practice-based research investigates the experiences of K-12 educators' agency and capability to employ data-use interventions in light of their professional contexts (e.g., Ahren et al., 2008; Coburn & Turner, 2012; Spillane, 2012). From this research, we have some insight into why and how instructional data-use interventions are effective (or not). For instance, we know that educators must find instructional data relevant and meaningful concerning their teaching realities to consider changing their teaching practices in light of it (Spillane, 2012). In addition, we know that K-12 educators appreciate talking with other educators about data, including how to interpret it in light of practice (Coburn & Turner, 2012). Furthermore, educators' data use happens in light of larger contextual complexities. Institutional norms and structures, including departmental and social networks, can influence educators' access to and practices around data, including the knowledge and skills they need to analyze and use data to improve instruction (Coburn & Turner, 2012; Datnow & Hubbard, 2016; R. Halverson et al., 2005). Research in K-12 educators' successful interventions that target educator's data-use practices can lead to meaningful and more reliable assessments of students' learning (Mandinach, 2012).

What We Know About Postsecondary Faculty's Instructional Data-Use Practices

While the above K-12-focused research provides some important insights, we need empirical evidence that examines how postsecondary educators use instructional data (Bouwma-Gearhart, 2021). Limited empirical research indicates that most postsecondary educators may not consider collecting and reflecting on instructional data to be their responsibility (Blaich & Wise, 2010). In addition, faculty may not have access to meaningful instructional data that they feel can inform their teaching (Blaich & Wise, 2010), including those in the STEM disciplines (Bouwma-Gearhart, 2021; Bouwma-Gearhart & Hora, 2016). Faculty also may not feel confident or competent in analyzing instructional data (Andrews & Lemons, 2015; Jenkins & Kerrigan, 2008). They may not have adequate time or appropriate resources or tools to engage in data-driven decision-making concerning instructional practices (Anderson et al., 2006; Hora et al., 2017).

Even those postsecondary educators trained in STEM disciplines, where effective data collection skills and use may be assumed, had shown more limited instructional data use, even when data was made available to them. In one study, Bouwma-Gearhart and Hora and colleagues (Bouwma-Gearhart, 2021; Bouwma-

Gearhart & Hora, 2016; Hora et al., 2017) explored the instructional data-use practices of 59 STEM faculty and 20 administrators at three institutions. Faculty noted they collected instructional data due to accreditation requirements and policies related to departmental reviews, but less so as part of their other instructional decision-making processes. Departmental and institutional interventions designed to improve faculty use of instructional data had low impact due to limits to faculty time and their lack of expertise with using teaching-related data. Notably, faculty found the availability of instructional data experts at their institutions to be an affordance, such as other faculty and staff, sometimes located in centers for teaching and learning. Faculty were more likely to implement instructional data-use practices and types of data if they aligned with their overall instructional goals. They generally found institutionally collected data, such as student evaluations, to be unreliable and insufficient, which discouraged their use of this data and provided motivation to create and implement some other instructional data practices. Although many faculty did not implement many instructional data-use practices, they found that those who did across their wide sample used various instructional data-use practices, both quantitative and qualitative. Decisions regarding data analysis that applied to practice included altering future versions of the courses based on analysis of exams and altering the pace of teaching, including time spent on particular topics.

While the above studies are helpful in understanding faculty use of instructional data, we need additional research to confirm or test these limited findings. Much of the scholarship related to arguments for the use by postsecondary educators of instruction-related data is anecdotal with limited empirical rooting

(Bouwma-Gearhart & Collins, 2015). What we do know about these faculty members comes from one study of STEM faculty from three universities (i.e., Bouwma-Gearhart, 2021; Bouwma-Gearhart & Hora, 2016; Hora et al., 2017). Specifically, we need additional inquiry about faculty realities that may drive interventions, development, and implementation to serve as affordances for what happens when faculty interact with data in their work (Coburn & Turner, 2012). Additionally, while instructional technologies hold the promise of influencing faculty's collection and use of data and the ability to involve students more in the learning process, we largely lack evidence of this promise for these educators. Further, given the increased recognition of the value of involving students in reflecting on their learning, more research is needed on how STEM faculty can foster and engage students in reflecting on data around their learning (Evans, 2013; Nicol & Macfarlane-Dick, 2006). Knowledge of these phenomena can assist in designing effective supports for faculty to more frequently and better use instructional data to improve their teaching and student learning, ultimately translating into greater success for students (Taras, 2002).

Instructional Technology that Influences Instructional Data-use Practices

One affordance championed for faculty collection and instructional data-use practices is instructional technologies (e.g., electronic learning platforms and their analytics tools). Behind the push for faculty to use these tools are assumptions around the easy and quick collection and basic analyses of learning-related data they can provide (Kuh et al., 2015). Studies suggest faculty adoption and use of instructional technologies is slow and inconsistent (Hora & Holden, 2013). In a report, Lester et al. (2017) state much of the research around instructional technologies focuses on the different types of technology tools that faculty and institutions may use (e.g., clickers, learning management systems, adaptive learning). This research includes how technologies are adopted and adapted by institutions and their use and perceived usefulness by students of these tools. Lester and colleagues also state a paucity of research on faculty pedagogical changes resulting from using instructional technologies. However, they suggest insights gained from research around individual faculty decisions to incorporate other innovations into their teaching practices can inform faculty use of instructional technology. Specifically, they cited research that has identified faculty identity and beliefs established through disciplinary socialization and behaviors that can affect decision making (e.g., Austin, 2011; Fairweather, 2008; Hora & Holden, 2013).

Although instructional technologies may be appreciated by faculty as a potential means to improve teaching and learning, other studies found that many instructional technologies were not used to their fullest potential. Klein et al. (2019), in a study of six faculty and 21 advising staff, identified barriers to effective use included a lack of reliable data infrastructure that was deemed cumbersome and misaligned with user needs as a deterrent to technology use. In another study, Hora and Holden (2013) interviewed and observed 40 faculty in STEM departments at three universities in the U.S. Not surprisingly, perhaps, they found that faculty use of instructional technologies largely depended on its availability (or not). They also found faculty use turned on faculty perceptions of relevance to and alignment with their pre-existing beliefs and instruction goals, meaning faculty needed to see the instructional tool supporting their pedagogical practices. They also found that faculty members' prior experiences with the technology and the perceived affordance of particular tools influenced their use. These studies suggest that faculty use of instructional technologies, and the promise of such for their instructional data use practices, may be more complex than just access to technology. Still, more research is needed in this area to confirm or challenge these limited findings and provide insight into how faculty use instructional technology to inform decisions related to their teaching practices.

Instructional Data-Use Practices that Involve Students Reflecting on Their Learning

Calls for research investigating instructional data-use practices that involve students reflecting on their own learning-related data are growing as faculty are encouraged to shift their instructional practices from teacher-centered to more learner-centered approaches (Blaich & Wise, 2010). Faculty must shift their thinking from seeing their role, primarily, as a transmitter of knowledge to one that empowers students in their own learning and provides students more meaningful feedback around their learning, beyond only results of summative assessments and final grades (Poulos & Mahony, 2008; Sadler, 2010; Taras, 2002). Ryan and Ryan (2015) assert that including students in reflecting on their learning data is more than just sharing grades or exams with them. They state that students reflecting on their learning have generally included having students complete structured and unstructured reflective journaling, formal reflective papers, interviewing, and group memory work. Ryan and Ryan acknowledge the value of these activities but contend that examples of faculty engaging their students in systematic and deliberate activities that involve reflective learning are rare. The researchers noted potential barriers that influence faculty engagement of students in reflecting on their learning, including factors related to students' socio-cognitive abilities. These factors include students' developmental stages, such as whether they were in their first year or a later year of study in the discipline or field of study. The faculty's use of reflective practices was also influenced by the context and potential complexity of the discipline in which the learning occurred. A final factor that may influence faculty when engaging students in reflective learning is the diversity of learners who bring prior knowledge, abilities, and experiences that may add to the challenges faculty may encounter when engaging students in reflective learning practices (Ryan & Ryan, 2015).

Indeed, the faculty's use of instructional activities that have students reflecting on their learning data has been shown to foster student learning of course content and instill a greater sense of accountability for their learning (Taras, 2002). Some research results seem promising, demonstrating that some STEM faculty are meeting researchers' calls to engage students in reflecting on their learning-related data (e.g., Nicol & Macfarlane-Dick, 2006). Nonetheless, more research is needed that investigates how faculty use their instructional data to design activities that engage students more in reflecting on their data.

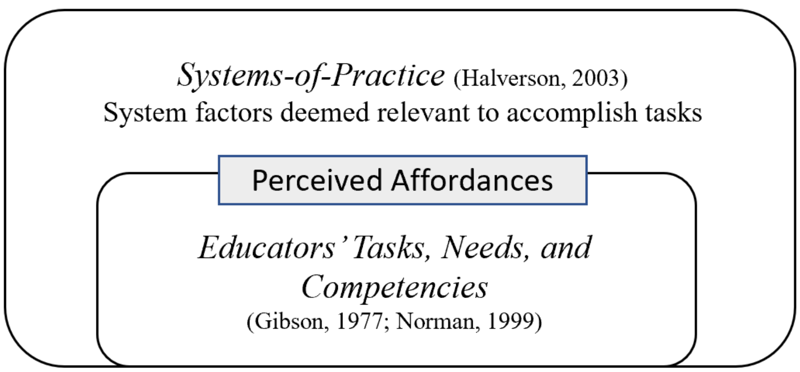
Paper Focus

This paper details an exploratory study conducted at one U.S. research university of STEM faculty members' instructional data-use practices. Specific findings confirm the work of Bouwma-Gearhart and Hora et al. studies, including faculty constraints to their data-use practices such as lack of time needed to implement data-use practices, standardization of course content that constrained some types of data collection, and a perceived lack of confidence and competence in their instructional data-use practices (Bouwma-Gearhart, 2021; Hora et al., 2017). Novel findings include faculty descriptions of instructional technologies that they claimed allowed more timely and complete data to respond to more immediately in practice. Faculty who used adaptive learning technologies specifically claimed it helped them collect more nuanced data on achievement trends for different groups of students. Although all faculty used summative data (i.e., exams, written assignments), several faculty described less reliance on these typical data indicators of student learning, rather using other practices such as group work to measure student learning. Faculty were mixed in their practice of engaging students in reflecting on their own learning data. These practices were generally described as activities in which students were asked to reflect on their overall performance in class and how their use of study techniques may (or not) be helping them. We discuss the affordances and constraints that faculty perceive in their instructional data-use practices. We also discuss implications for departmental and institutional leaders, faculty leaders, professional developers, and for faculty themselves.

Conceptual Frameworks

We assume faculty work within "complex network[s] of structures, tasks, and traditions that create and facilitate practice" (R. R. Halverson, 2003, p. 2), which Halverson terms *systems-of-practice*. Faculty encounter in their systems-of-practice structures such as procedural norms and policies, physical objects and tools, and activities that can serve as affordances and impediments to their work (see Figure 1). *Perceived affordance theory* (Gibson, 1977; Norman, 1999) is also relevant to our study as it helps to explain how and which structures and activities are salient to faculty and impact their practice. *Perceived affordances* are factors in the system that faculty sense and deem relevant around a task related to their self-perceived ability to attend to the task (Bouwma-Gearhart, Lenz, et al., 2018; Norman, 1999). As examples, affordances can be structures or activities that educators believe will allow (or inspire) them to engage in collecting and using instructional data. For instance, educators may use instructional technologies, such as clickers, to collect certain types of instructional data of their interest, assuming they have some competency to use the tool.

Figure 1
Conceptual Framework: Integrating Perceived Affordances and Systems-of-Practice Theories



Affordance theory has been used by other researchers who recognize postsecondary educators as functioning within complex socio-cultural systems. Hora (2012) found that structural and socio-cultural factors afforded and constrained teaching practices. Affordances included the high degree of autonomy faculty had in making decisions related to their teaching practices. Constraints included policy implications related to issues such as promotion and tenure requirements. As demonstrated in some of this past research, affordances are not always positive for an educators' actions or insights (Norman, 1999). Affordances may also be barriers to action (Bouwma-Gearhart, Ivanovitch, et al., 2018). For instance, Bouwma-Gearhart and colleagues found that frequent formative assessments that took up class time could act as barriers if faculty felt pressed to cover large quantities of specific types of content. We use perceived affordance theory to illuminate the realities of educators operating in complex socio-cultural systems in light of their professional realities, including their pedagogical knowledge, skills, norms, and felt competencies.

Methods

Research Questions

Our exploratory research is guided by the following questions:

1. What are the instructional data-use practices of a sample of STEM faculty from one U.S. research university? How do they think these inform their teaching?
2. What affordances and constraints, including instructional technologies, do these faculty claim regarding their instructional data-use practices?
3. To what extent do faculty engage students in reflecting on their own learning data?

Study Context

This study took place at one large university in the United States, classified in the Carnegie Classification of Institutions of Higher Education (n.d.) as a *doctoral university with the highest research activity*. A comprehensive (campus-wide) STEM education improvement initiative was underway to foster evidence-based instructional improvements in large-enrollment, lower-division STEM courses by leveraging the distributed expertise of faculty to learn from one another. Funded by the National Science Foundation, a project research goal was to investigate changing faculty perceptions of teaching and their teaching-related practices in light of the initiative activities. This paper centers around findings from interview data collected near the end of the initiative, in 2017, specifically around the questions exploring faculty instructional data-use practices.

Participant Sample and Data Collection

Prior to collecting the interview data that roots this paper, surveys were sent to 420 faculty across STEM disciplines with 127 faculty responding, a 30% response rate. Table 1 shows the total number of survey respondents in each of the disciplines surveyed.

Table 1
Faculty Respondents in STEM Disciplines

Physics		Chemistry		Biology		Mathematics		Engineering		Total	
n	%	n	%	n	%	n	%	n	%	n	%
12	9	18	14	13	10	27	21	57	45	127	30

N = 420 (n = respondents); *Engineering includes civil, chemical, biological & mechanical

Quantitative survey data were collected to ascertain the influence of the initiative's various aspects and inform subsequent interview protocol development. While the survey, and interviews, focused on various aspects of the teaching of interest to the larger NSF-funded project, this paper focuses solely on faculty experiences around instructional data use.

We used descriptive analysis from three survey questions to probe for faculty perceptions of the larger group regarding their gathering, analyzing, and responding to data that informed their teaching. Respondents indicated their level of agreement on a scale of 0 (Not true at all), 2 (Somewhat true), and 4 (Very true) to the following prompts:

1. I know how to gather, analyze, and respond to data that informs my teaching.
2. I regularly gather, analyze, and respond to data that informs my teaching.
3. I am committed to gathering, analyzing, and responding to data that informs my teaching.

When faculty were asked if they regularly gather, analyze, and respond to data that informs their teaching, the results of the 127 faculty surveyed were a mean score of 2.50 ("somewhat true" on a 5-point scale; SD = 1.04). Faculty indicated a slightly higher mean of 2.74 ("somewhat true"; SD - 1.02) when asked if they were committed to gathering, analyzing, and responding to data. Faculty indicated a mean score of 2.75 ("somewhat true"; SD= 0.94) when asked whether they knew how to gather, analyze, and respond to data that informed their teaching (see Table 2). A standard deviation of approximately one showed a relatively uniform view of faculty perceptions regarding instructional data use.

Table 2
Faculty Perceptions of Gathering, Analyzing, and Responding to Instructional Data

Survey Item	*M*[1]	*SD*
I know how to gather, analyze, and respond to data that informs my teaching.	2.75	0.94
I regularly gather, analyze, and respond to data that informs my teaching.	2.50	1.04
I am committed to gathering, analyzing, and responding to data that informs my teaching.	2.74	1.02

[1] Variable mean coded on a 5-point scale of 0 = “Not true at all,” 2 = “Somewhat true,” 4 = “Very true” (n = 127)

These survey results prompted us to explore instructional data use in interviews to allow richer data around these issues. From those responding to the survey, invitations were sent to faculty across the represented disciplines to conduct interviews. Nineteen out of twenty-one faculty invitees consented to interviews (90% response rate). (See Appendix A for full interview protocol). An external project evaluator conducted the semi-structured interviews, which lasted approximately one hour.

Table 3 shows disciplines, participant pseudonyms, and professional positions for the 19 STEM faculty who participated in the interviews for this study. Faculty disciplines included physics, biology, chemistry, mathematics, and engineering (chemical, biological, environmental, and mechanical engineering). Nine of the faculty were in tenure-track faculty positions (assistant, associate, and full professor), and ten were in fixed-term faculty positions (instructor and senior instructor). Participants had taught at least one lower-division STEM course in the previous year and were involved in the campus initiative. Race/ethnicity and gender data were not collected in this study, and we do not want to make assumptions about participants' identities. We were further concerned with ensuring anonymity given the sample size, identification of disciplines, and professional positions of a group of faculty from just one university. Thus, we use pseudonyms that we perceive as gender neutral.

Table 3

List of Disciplines, Participants' Pseudonyms, and Participants' Professional Positions

Discipline	Participant	Professional Position
Physics	Robin	Fixed-Term Faculty
	Jamie	Tenure-Track Faculty
Chemistry	Jordan	Fixed-Term Faculty
	Alex	Fixed-Term Faculty
	Sidney	Fixed-Term Faculty
	Casey	Fixed-Term Faculty
	Tracy	Tenure-Track Faculty
Biology	Jodi	Fixed-Term Faculty
	Peyton	Fixed-Term Faculty
Mathematics	Leslie	Tenure-Track Faculty
	Jackson	Fixed-Term Faculty
	Madison	Fixed-Term Faculty
	Kelly	Fixed-Term Faculty
	Drew	Tenure-Track Faculty
	Shannon	Tenure-Track Faculty
Engineering	Lee	Tenure-Track Faculty
	Bailey	Tenure-Track Faculty
	Logan	Tenure-Track Faculty
	Lynn	Tenure-Track Faculty

Note. N = 19. Tenure-Track Faculty include assistant, associate, & full professors, Fixed-Term Faculty include instructors & senior instructors.

Data Analysis

Data analyzed from the interviews for this paper pertained to the following questions:

1. I'd like to hear more about your assessment practices while teaching.
    a. To what extent do you collect data/information about student learning?
    b. Are your teaching practices informed by data/information about student learning?
    c. Are there means in the classes/courses that you teach for students to reflect on their own learning data? [If yes], Can you detail these processes?

Interviews were transcribed verbatim and transferred to Dedoose coding software for qualitative analysis. The first author created inductive codes from a first read of the verbatim transcripts, drawing perspectives from interviewees' own words in response to interview questions (Auerbach & Silverstein, 2003). We attempted to stay grounded in faculty descriptions and matching those with definitions of the concepts. During both rounds of coding and analysis, the first analyst created theoretical memos (Montgomery & Bailey, 2007) to provide a record of developing ideas and interconnections.

We used several methods put forth by Creswell (2014, pp. 201–202) to address our findings' trustworthiness. One method we used to ensure the trustworthiness of the analysis was *peer debriefing*. The second author supported the codes' development and participated in debriefing and data analysis sessions with the first author throughout the coding and analysis of the data. The second author also reviewed 20% of the coding to increase reliability and consistency and provide ongoing contributions to the emerging codebook. (See Appendix B for codes.) In both phases, the authors discussed emerging concepts and themes based on their critical reflections on the data, and an ongoing discussion of codes and interpretations addressed (dis)agreements within the data (Auerbach & Silverstein, 2003). At least two interviewees made all the claims we report in this paper. We included exact numbers of participants in conveying claims.

Limitations

We acknowledge the multiple limitations of our research. For one, our study took place at one institution with one improvement initiative targeting select STEM disciplines. Overall, our exploratory study is based on a small sample size, with some claims voiced by a few and, in some cases, two participants. As well, faculty who agreed to be interviewed may represent a biased sample of faculty who were engaged in making improvements via some affiliation with a campus-based improvement initiative, thus, and may not fully reflect the larger population of STEM faculty. Disciplinary norms and practices, which may influence faculty practices and perspectives, were also not explored per limited sample size. Finally, we did not collect observations of faculty practices or student perceptions of their teaching and learning experiences.

Findings

Types of Instructional Data Faculty Collected

Summative Data-Use Practices

All faculty indicated that they collected summative data to inform them about their students' learning. Summative instructional data generally included a combination of mid-term and final exams, quizzes, and, to a lesser extent, written assignments. Typically, these assessments were quantitative (e.g., multiple-choice) if class sizes were large and generally administered two to three times during the term. A majority of faculty perceived summative evaluations as an effective measure of student learning and determinants of grades.

Robin (physics) indicated that 70% of their students' grades came from exams, including two exams around "mid-term" and a final course exam. They felt these types of assessments, and the data they generated, gave them the best opportunity to know what an individual student comprehended.

> *Let's start by saying roughly 70% of my student grades come from exams. There's two midterms, and a final and those are the best way that I know that*

> *student is presenting me the information that they personally know and they're not working with others.*

Alex, a chemistry instructor, described these summative data-use practices as "traditional," utilized, in part, because of the significant number of students in their classes. They described weekly individual quizzes, midterm, and final exams consisting primarily of multiple-choice questions out of necessity, although they did have some open-ended questions on the exams.

> *We do very traditional assessments in a sense because, in the fall term, we have fourteen hundred students. We have ten weekly quizzes, and those are individual. We have ten small group activities, one per week. We have two midterm exams and a final consisting of a section of multiple-choice, which is out of practicality, and about forty percent of that exam is open-ended, so it's free-response for students.*

Perception of Changes to Summative Data Practices

While acknowledging the need for summative data-use practices, some faculty also signaled their data practices were shifting away from typical exams as the only determinant of student learning to other means such as group exams. A few faculty (4) described how they felt relying only on summative data-use practices was problematic, per student diversity and in terms of data quality. Two faculty indicated concern that typical means of gathering summative data (e.g., exams) did not allow all students ample opportunities to show what they had learned and, thus, did not accurately reflect student progress. These faculty also felt typical exams did not provide them with sufficient data to determine students' course grades and sought to minimize the use of summative data-use practices as the primary determinant of these grades.

Tracy, a chemistry instructor, exemplified both of these findings. Tracy described a shift they had made away from exams as the sole determination of students' grades to a grading structure that allowed for over fifty percent of the final grade determined by students' work on papers, class presentations, online work. Some of these activities involved group work. Nonetheless, they were considered a significant part of the grade students earned. Tracy discussed how they were deemphasizing formal exams and a desire to engage students more actively in the material. Tracy stated,

> *This year was a pretty dramatic change to over fifty percent of the grade, and the assessment was not exam-based. So the students were writing papers, which they got formative feedback on, and they were developing presentations that they gave in class and also published on the website where they also had some feedback and revision steps there. Teaching assistants were assigned to some of those activities, so they hopefully got some fairly frequent feedback. Most people were working in groups rather than individually on some of those assignments, sharing their results, presenting them, and all of that was pretty high stakes because the total for those activities like I said, was over half the grade. So we deemphasized formal exams, there were midterms and final exams, but they were lower stakes. That came out of both the desire to get students more actively engaged in the material. On the assessment end, I think we've recognized, I've seen over many years, that exams are great for many students, but I think they don't measure all student activity and success and learning.*

Tracy perceived that adding different student assessments to their teaching repertoire resulted in more traditional ones feeling like 'lower stakes" for students.

Formative Data-Use Practices

Nine faculty (47%) described engaging in collecting formative instructional data, which they felt gave them immediate information about student learning. These included qualitative forms of data, either curricular artifacts or verbal information qualitatively gathered from students. Nine faculty (47%) described collecting this type of formative data, described as "submission sheets," "exit points," "muddiest points," or "Tuesday problem." These activities required students to evaluate or respond to a question or statement related to course content. These activities resulted in data artifacts that faculty stated informed them about their students, learning, and interests. These activities were often described as "low stakes" for students, supposedly concerning more typical assessments of their learning (e.g., formal exams).

Drew, a mathematics instructor, described using "exit cards" at the end of class to assess students' level of understanding or confusion. They allowed students to be anonymous in their submission. They described this activity as giving them a quick opportunity to see what students were learning and what might need to be addressed again. They said it in this way, indicating some benefit of the anonymous, low-states (not graded) nature of the activity for students.

> *In terms of formative assessment, I have used things like exit cards, where at the end of a class, I just have students [write down a question or comment]. There's no grade at all attached to this. It's just for me to get some sense of what did you [student] think was the most significant thing you learned today, what was the muddiest point. These kinds of quick questions that people jot down on a card and can even be anonymous, and then a quick look through all of that gives me a sense of, 'oh wow,' I really missed the boat here. I need to re-address that topic again*

Lee, an engineering instructor, talked about using "muddiest point" activities that gave him information about topics that students wanted to know more about. Lee also perceived these formative assessments providing him data about students' understanding of the concepts and via a low-stress activity to assess their level of understanding. Lee stated that the activity allowed insight into

> *...whether they want more coverage on a specific subject. In terms of reflecting on their own performance, I certainly think that when you make an assignment like full credit for participation or sort of the check if they are there working and engaged, it also sends a message to them about how they engage in the material. Both of those were sort of meant to reward them for being there and engaging, but not making it so high stakes, so it wasn't supposed to be a stress out sort of thing.*

Lee also felt giving credit for these kinds of assignments sent a message to students about the importance of attendance and being engaged in the assignments. Like Drew, Lee discussed this being lower stakes for the students.

Lynn, another engineering instructor, described using an activity they called "the Tuesday problem." This activity would give students a problem to work on during a break during a class. After the break, they walked around to observe and help students who presented as needing extra attention. Like Drew and Lee, Lynn indicated this activity gave them an informal way to engage with students, resulting in a less stressful assessment activity for them. Lynn described it this way,

> *The Tuesday problem or something like this, where I take a break in a two-hour lecture, a ten-minute break, and I put up a problem, and I say you guys are welcome to solve it or not, but when we get back from the ten minutes I'll solve it, and then we'll talk about it, and you put it up, and you walk around, and you see if people are trying and you kind of help them, or you give them pointers on what direction to go. So there is a way to create way more informal engagement by doing things that way because there's very little stress because it doesn't count for any points, really.*

As Lynn also alluded to, faculty also detailed gathering verbal forms of data (i.e., talking with others) to provide them with information about their students' learning. Six faculty (32%) spoke of collecting instructional data through verbal interactions with students, usually informally, to gather information.

Jordan, a chemistry instructor, spoke about providing an open environment for students to discuss challenges and fears. They described how talking and interacting with students allowed them to "*have a discussion about the growing pains of going through science education.*" Sidney (chemistry) said that informal interactions with students gave them some of the most valuable instructional data they collected. They describe how most of their assessments, depending on the course, were done through these informal, information-gathering interactions with students to determine if students liked the course or what parts they did not like.

> *Most of my assessment, and I think this is true for most people, comes from informal interactions. Of course, it depends on the course, but oftentimes I informally really try to just talk to students as much as I can and see how things are going. I often say, 'Hey, what do you like about the course? What don't you like?'—again, about as informal as could be, but I sometimes find those are most valuable.*

Another faculty, Bailey (engineering), similarly talked about informal interactions with students to gather information about their courses. They indicated using their office hours and visits from students to ask them questions about how they were feeling about the content that was being taught. They even probed via questions to students about whether students understood a particular concept that the instructor was trying to convey.

> *Then students in office hours, if they seem willing, I'll often ask how do you feel about this content area, or even more specific things like I tried to tell you this, did you notice that in class, or do I need to do that differently.*

Another faculty, Peyton (biology), talked about meeting with students frequently to assess what students were saying to understand where they were and where the instructor thought they ought to be. Peyton said, "*I meet with my students a lot, so I hear what they're saying, and I use that to inform where they're at and where I think they need to be.*"

Two faculty described how talking with their teaching or learning assistants provided them insight into student learning. In this excerpt, Robin (physics) described a learning assistant program they developed that allowed them another way to collect formative types of data on students. During weekly meetings, the learning assistants provide feedback to the instructor about students, including what they perceived to be working or not working. Robin said,

> *Qualitatively, I'm talking to my students constantly. I've developed a learning assistant program, so I have ten learning assistants, and they're constantly giving me feedback about what's working, what's not working, helping me try to guide the students. And I have seven T.A.'s [teaching assistants] at any given moment, and we also have meetings every week.*

Affordances that Influenced Instructional Data-Use Practices

Faculty and Organizational Student Assessment Norms

We also found several affordances that influenced the instructional data-use practices of faculty. Not surprisingly, they often pointed to data they collected that provided insight around their teaching as data types and means that were norms for them as practitioners and within their larger organizations. For example, more traditional types of student learning assessments (i.e., exams, written assignments) remained privileged by faculty and their departments. Thus, faculty kept using them and claimed to be informed of students' progress via them. Nevertheless, many faculty also claimed a desire for other data to inform them in ways that more traditional assessments did not. Narrative and verbal types of data, for some students, provided them novel data around students' understanding and provided them more timely feedback for more immediate response to students, like "submission sheets," "exit points," "muddiest points," or the "Tuesday problem" exercise. Generally, faculty relied on "tried and true" methods, like course exams, to gather summative, often quantitative data to inform their teaching. When they sought different or more complete information or to help students feel more comfortable and relaxed in providing them with information around their learning, some faculty gathered and utilized other data, namely formative and largely qualitative.

Learning and teaching assistants were another affordance that two faculty used to gather data on students' performance. As described by one faculty, the development of a learning assistant program afforded them feedback on what was working or not related to students' learning.

Instructional Technologies

Eleven faculty (58%) reported instructional technologies afforded them opportunities to collect and analyze data to inform their teaching. These included audience response systems (i.e., *clickers*), online platforms for homework or other course materials, and adaptive learning technologies. Overall, faculty detailed these technologies in comparison to when they did not have them or had to rely on more traditional, or lower-tech data gathering means. The instructional technologies allowed more timely and complete data to respond to more immediately in practice.

Several faculty used clickers, which they claimed provided them in-the-moment snapshots of students' levels of understanding and the opportunity to correct student (mis)comprehensions. Peyton, a biology instructor, noted that if the class scored below 85% on the clicker question, they knew they needed to add an immediate class discussion, asking students to explain why they chose their answers. Peyton explained,

> *Whenever we have a clicker response that's less than 85%, we'll spend time talking about why the right answer is right, why the wrong answer is wrong, and I'm always soliciting their voices for that. I've moved away from me explaining to getting them to explain and then affirming.*

Several faculty discussed the formative nature of the data they were collecting. In this example, Peyton (biology) again described doing formative assessment using clickers, alongside having students complete daily group assessments that they could then read after class to inform subsequent teaching practice. Peyton said,

> *I do formative assessment in my classes through clickers, but I also have daily what I call submission sheets, so the groups work together to answer a couple of concept type questions, and they turn those into me, and I read those each day.*

Several faculty talked about having students complete homework and pre-class quizzes on online platforms, which they claimed afforded them a quick, formative assessment of student comprehension, allowing them more immediate adjustment to their instructional practices. For example, Sidney, a chemistry instructor, noted that students took a pre-class quiz after first viewing a video in an online course environment. Before the class session, Sidney would meet with colleagues who were also teaching the class to discuss understanding as reflected by the quizzes across the complete array of students in the course. Sidney noted they had built flexibility into their courses to adjust their instruction to accommodate any changes that such data indicated the need for. Sidney stated this process was an improvement to trying to ascertain student understanding from, perhaps, fewer students that they could check in with in class.

> *Students are supposed to take a pre-class quiz, but the catch is that in order to be able to access it, they have to have first viewed the video. So ideally, it sort of forces them to watch the video and then take the quiz. The nice thing was*

> *that I and the colleague I taught with, we would have a discussion before class every time of, 'Hey, what questions on the quiz were they really getting? Which questions didn't they get?'... we were flexible enough that we could go into class that day and say, 'Hey, you know we realized we should spend a little more time on this.' That was a huge change that we hadn't [done previously]—we might have gotten a feel for it kind of walking around talking to students, but there we had very nice concrete data to inform what we would do and enough flexibility built in that we could say, 'Hey, today we're going to spend some more time going through Topic A quickly because most of you seem to be fine with that and spend more time on Topic B.*

Two faculty described adaptive learning technologies as affording them more immediately actionable data around their students' learning. Alex (chemistry) described adaptive technology as "a real eye-opener" related to their ability to respond and change their curriculum within days.

> *Adaptive learning has certainly been a refinement that I made because I went from an adaptive learning model where changes were being made to the curriculum based on student understanding, perhaps term by term, and now I've shortened that gap where feedback is immediate, evaluation is immediate, and then changes could be made for the very next assignment, which would be the next meeting. So I think that has been a real eye-opener in refining the response time, in that a change to the curriculum is not occurring the next term it's occurring within the term, and, as a matter of fact, up to within two days.*

Jodi (biology) found the adaptive learning technologies helpful in understanding trends over time and particularly useful in understanding how underrepresented and first-generation students were doing and where they might need more support.

> *I think the predictive analytics things are useful if it's things like underrepresented minorities, first-generation college students, information like that, like more of the demographics of who my students are to figure out if there are pockets of the population that aren't doing really well in the class.*

Impediments to Instructional Data-Use Practices

Faculty perceived several impediments to their instructional data-use practices. Constraints included (a) a perceived lack of time needed to implement instructional data-use practices, (b) standardization of course content, and (c) perceived lack of confidence and competence in instructional data-use practices.

Perceived Lack of Time to Engage in Instructional Data-Use Practices

Six faculty described how some instructional data-use practices took a great deal of time to implement and were therefore difficult to utilize effectively. Casey, a chemistry instructor, said that time constraints hindered their ability to try new or innovative practices, and they viewed this as a problem with implementing new practices.

> *Time constraints definitely hinder it [data-use practices], and they hinder actually doing anything innovative. That's actually a huge problem.*

Madison, a mathematics instructor, saw instructional data-use practices as necessary, but those practices were often pushed to the side by other instructional activities. They said, "*Important things [like collecting instructional data] go to the back burner when the rubber hits the road, even when you know they're important.*" One faculty talked about the difficulty of fitting the instructional data-use practices into their curriculum. They wanted to do more and thought it was necessary but felt constrained by established practices.

> *That's definitely something I've wanted to do more of, just the issue of where do you fit that into the curriculum, but I think that's important, and I wish I was doing more.*

Two faculty stated their instructional data-use practices were constrained by a lack of time often taught large classes. Casey, chemistry, elaborated that large class size can equate with a lack of time to implement instructional data-use practices, at least ones they felt significant. They described having students complete short writing assignments if students were struggling. Although they acknowledged that students gained from this experience, they also acknowledged that this type of practice was difficult to do with hundreds of students to measure student learning. Casey said,

> *A lot of times, I'll do a short writing assignment, especially if I think they're struggling with a concept, I'll have them write about it. But there's hundreds of them, so it's difficult to get a lot out of that, although the students get a lot out of it.*

Madison, mathematics, felt constrained by class sizes and the number of classes that instructors taught per quarter, and other responsibilities that influence data use practices such as making exams predominantly multiple-choice.

> *Because of the class sizes and some people are teaching, some of the instructors are teaching four courses per quarter. I have another portion of my job is managing the math learning center, so I usually only teach three, but when they have that size classes, a large portion of the exam needs to be multiple choice*

Constraints Due to the Standardization of Course Content

Several faculty (5) perceived constraints in using different kinds of instructional data-use practices due to the "standardization" of course content taught by various faculty and usually indicated requirements for standardized exams and grading policies. In some cases, these constraints were tied to whether the course was a sizable lower-division course taught by several faculty simultaneously at the same institution. In other cases, faculty described being constrained in their practices if the course was also taught at a community college or as a dual credit option in local high schools. While all faculty indicated they had autonomy concerning *how* they taught, several faculty indicated they were constrained by requirements related to student assessments of learning. Kelly, mathematics, said, "*Most of the assessment I do is out of my control. Sixty-five to seventy-five percent of the grade for the courses I teach have to come from two midterms and a final.*" Notably, such realities were most often detailed by mathematics faculty. Still, Kelly talked about moving towards more group exams, a novel practice, and described the reluctance (i.e., constraint) within their department to adopt this practice.

> *I'm slowly trying to have conversations with the powers that be in the department to be adjustable [with doing exams] so maybe we'll do group exams, or maybe we'll try some other things other than just those very traditional midterm and final exam structures.*

Perceived Lack of Confidence and Competence in Instructional-Data Use Practices

Several faculty (4) stated a lack of confidence and competence in collecting and using instructional data to inform teaching practices. Bailey, an engineering instructor, described their instructional data-use practices as "terrible" in relation to more effective practices that they knew existed but did not know enough to implement.

> *Yeah, they're [instructional data-use practices] terrible. I know enough to reject a lot of common practices, but not enough to replace them with better alternatives. So I am really struggling with that right now. It's not formulated at all.*

Leslie (mathematics) also perceived instructional data-use practices as the weakest part of their teaching. They understood the importance of assessing student learning and formative practices specifically but struggled to respond to data in their teaching practice directly.

> *I would say that's probably the weakest part of my teaching practice. I'm not really formal about incorporating results of assessment into teaching, which sounds pretty bad. Yeah. Formative assessment, I read the literature, I drink the kool-aid, but that is the thing I drop the most in terms of my teaching practice. What I do is so informal. I don't know if I can even describe it.*

Another faculty was uncomfortable with their colleagues finding out about their instructional data-use practices. They perceived pushback that could result, partially based on their already being seen as an outsider in their field per their gender. They did not want to advertise what they did differently because of the possible repercussions they would experience.

> *You know, gender-wise, honestly, I've come into this profession, and I've been an outsider. I'm not going to take something I do that's different than what other faculty members do and advertise it. I may be very successful at it, but if I advertise it, there will be repercussions.*

Engaging Students in Reflecting on Their Own Learning Data

The overall sample was mixed in their practice of engaging students in reflecting on their own learning data. A slight majority of faculty (n=10, 53%) indicated that they did not implement any instructional practices for students to engage with or reflect on data around their learning. Of these instructors, five instructors stated they did use formative data to inform their teaching practices. However, they did not explicitly use these data to engage students in reflecting on their learning. Lynn, engineering, described providing students with exam scores, a bell curve showing averages, and the range of grades, but no other data. When asked if students had an opportunity to reflect on their learning, they said,

> *Oh, no. Not aside for their own grades. They see averages and things like that. I guess that's really professor-dependent, but for me, whenever I go over the exam, I always put out the bell curve and say this is the average, this is the standard deviation, this is the range of grades.*

Two faculty mentioned the institution's end-of-term student evaluation of teaching survey as a means of students reflecting on their learning. One faculty stated they added a question to the survey related to whether students understood a particular concept covered in the course. Tracy, a chemistry teacher, said they would advocate for other faculty to do this kind of practice.

> *That's the one where we add the question on their electronic evaluation of teaching, so in the electronic evaluation of teaching for the students, there's a series of standard questions, I think there's ten, how was the course basically, what was the instructor's contribution to the course and there's a few others, and then I add, and I advocate for all other faculty to do this as well, you add at the end of this course [a specific question related to the content].*

Still, around half of the faculty (n = 9, 47%) indicated they implement instructional practices that engaged students in reflecting on their learning data. These practices were generally described as activities in which students were asked to reflect on their overall performance in class and how their use of study techniques may (or not) be helping them. Jordan, a chemistry instructor, stated, "*I really try to actively engage them in utilizing critical self-review and then coming together with others once that review has taken place to gather the information necessary to move forward."*

Alex (chemistry) described posing to students open-ended questions on worksheets, asking them to describe whether they understood the material and how comfortable they were with their learning. Alex perceived this type of student reflection as allowing students more autonomy with their learning.

> *[in the student's voice] "I understood this material, I feel comfortable with this material," and then they [students] produce a little bit of evidence and they will say things like "I am completely lost on buffer systems, I have no idea what is happening in a buffer system. I don't even know what a buffer system is." I think that's part of the empowerment [of students]. I think that's part of their confidence in that this seems to be very meta. So, students are plugged into their empowerment and their own understanding. They're not looking at it as how I did on an exam. They're looking at it as, I think I get this, I'm supposed to be learning these key concepts.*

Drew, a mathematics instructor, had students keep a journal of their progress in understanding course concepts and any related difficulties. Students received credit for their reflections.

> *In some courses, I've gone as far as actually having students keep a journal of what they struggled with that they actually turn in with the homework. So there's actually some "credit" awarded for going through that exercise. But I think the bigger value of that is getting the students themselves to reflect on their own learning.*

Jodi, a biology instructor, had students do "real-time" writing in class in response to a question. They would write on a notecard and hand it in. While this served as formative feedback for Jodi around her practice, she also saw it as an opportunity for students to reflect on their learning data.

> *When I'm teaching in the classroom, I also have them do some real-time writing. I think writing is a really good way to start to help them see what they don't understand. So I have them do an individual note card where they write down an answer to a prompt, and then I have someone else, not me, read them, because there are seven hundred of them, and give me some summaries, and then I go back over that with them in the class as sort of a way to see if their thinking is right or what is a good response to these things versus what's not a good response to these things. So those are kind of the way I think that they get to reflect on what they're learning.*

Lee, engineering, used a formative instructional data-use practice, "the muddiest point type thing," to have students reflect on their level of understanding.

> *I often will do the muddiest point type thing, which has them reflect not so much on performance but on their level of understanding*

Two faculty described using peer or small group activities to afford students opportunities to reflect on their learning. Casey, chemistry, has students complete short writing assignments, especially if they struggle with a concept. They describe collecting the writing but also having students time to share in groups with assigned friends.

> *Sometimes they give them to me. They are in groups, they have assigned friends in my class, so they do share among their group members also.*

Kelly, a mathematics instructor, had students engage in self-reflective activities during a "recitation class," where students from a large-enrollment main class meet in smaller groups to work. Students discussed their homework assignments and compared answers to those given by the instructor.

> *It [student reflection on their own learning data] gets facilitated in smaller groups, in like a recitation situation. So normally my lecture would have a hundred people and then one day a week there's four different classes of twenty-five. When [students] get their written homework back with some sort of marks on it, they're encouraged to look over that and discuss the solutions that have been provided by me. They're asked to compare and contrast between what their answer looks like, what the solution organization looks like. It's the logical thought process of putting things together that I want them to focus on. So it's sort of done in small groups, face-to-face discussions.*

Discussion

Instructional Data-use Practices and Motivations

In this paper, we report on a study of STEM faculty members' instructional data-use practices, including the types of instructional data that faculty collected. In general, faculty claimed to use multiple instructional data-use practices to inform their teaching practices and their students' learning. We found that all faculty described mostly gathering data via summative assessments, such as midterm and final exams and weekly quizzes. While a few faculty also discussed written assignments they generally gathered, most data coming from summative assessments were qualitative in nature. Faculty indicated they used these assessments most often in classes they described as large-enrollment and generally administered them two or three times during the term. Most faculty perceived summative assessments as practical in providing measurements of student learning and determining grades. Several faculty indicated these were the only means for individual students to demonstrate what they had learned as opposed to other types of more formative assessments or group work.

However, a few faculty acknowledged that summative evaluations did not always reflect student progress. For these faculty, their perceptions of the value (i.e., importance) and function (i.e., purpose) of summative assessments had evolved to privilege more formative assessments. Several of these faculty indicated their concern that diverse students did not have ample opportunities to demonstrate their learning via more traditional and common (i.e., summative and qualitative in type) assessments, in essence questioning the quality of the data to inform their teaching. These practices minimized the impact of more common and traditional assessments on students' overall grades in the course. A small number of faculty were considering experimenting with students working in small groups and giving presentations, instead of formal exams, or having students take exams together; a practice that faculty perceived would need further discussion with department colleagues or leadership before implementing.

Roughly half of the faculty we interviewed also gathered formative data that they perceived gave them more immediate ways to assess student learning. Much of this data was qualitative in nature, collected via course artifacts or verbal exchanges. Such artifacts as "submission sheets" and "muddiest points" asked students to evaluate or respond to a prompt or question about the course content. The purpose of these novel strategies was to intentionally provide a more collaborative and inclusive process for students to demonstrate their learning that still offered them insight into students' learning and interests. Faculty also described these as less stressful ("low stakes") for students when compared to formal exams.

Some of these findings indicated an awareness on the part of faculty that not all students bring the same background and experience to STEM coursework, which would make more traditional and common assessments less than meaningful for them as educators. These faculty, thus, knew to implement other assessments that would allow a wider array of students to demonstrate the learning and progress faculty expected they were making. Faculty use of activities that provide students with "low stake" options seemed especially promising in promoting students' success across the diversity of learners in their courses. Through their implementation of these less stressful assessments, faculty also provided students means to ask for more review or coverage of particular topics. As they did this, faculty may have been engaging students in determining the pace and depth of content coverage, all the while sending a message to students about their role and agency in their learning. These faculty practices are promising per research that demonstrates a recognition of student achievement and faculty responsibility in creating more equitable learning environments (Guinier, 2015; McLaren, 2017).

Some of the formative data that faculty collected were of verbal form, described as some of the most informative data faculty collected about how students were doing in their courses. These included having an open discussion in class, talking to students during office hours, and talking with learning and teaching assistants about student progress. These findings are also promising, as faculty interactions with students are essential in building rapport and positive relationships with students (Kuh, 2003) and can ultimately enhance student success (Kahu & Nelson, 2018). Many of these interactions resulted in verbal data that were described as informal, such as asking students questions during office hours or talking with them one-on-one during class or as groups in work sessions. While we did not explore with faculty the proportion of students faculty connected with via these informal interactions, we assume that these informal interactions may not have involved all, or even most, students. There may, in fact, be a reason to be concerned that some students may find these interactions with faculty intimidating and be unwilling to share areas where they may be struggling due to their perceptions of the potential reactions of the faculty. Some students, additionally, may feel unable to initiate such interactions (as during office hour visits). This reality may position students not comfortable, agentic enough, or able to make time to talk with their instructors at a disadvantage (Kahu & Nelson, 2018; Shapiro & Sax, 2011), including those struggling as well as those succeeding, both groups that can provide faculty important insights into their teaching. A few faculty described using their learning and teaching assistants' assessments of student comfort and understanding of the material as indicators of student progress. This strategy provided indirect data gathering from students that may counteract our last concern, allowing faculty insight from students who do not feel comfortable talking to them directly. Faculty might consider fostering more of these interactions of their students with others who students may see more as peers to collect meaningful and timely, learning-related data to inform their teaching.

Too, we need to consider the potential limitations of data that faculty reported collecting, including that which may seem to be more anecdotal. Andrews and Lemons (2017) found that postsecondary biology faculty primarily relied on personal perceptions and experiences rather than empirical evidence to inform their teaching practice. They found that using data to convince faculty to change was ineffective. Indeed, this may be one reason that faculty may not be willing to change comfortable, already established practices, especially if departmental climates further stifle the implementation of novel practices. Professional developers and education leaders might need to help faculty recognize this limitation and find a "sweet spot" between the comfort, ease, and meaning they feel (for themselves and students) around verbal, informal formative data and data that is also valid and reliable. Faculty in our study indicated a concern for the meaningfulness of more common, traditional assessments such as multiple-choice exams that may not demonstrate student learning. Overall, our study points to how we must help them evaluate, modify, and create instructional data-use systems that sit at the intersection of being reliable and valid, as well as meaningful and usable. These systems must also be practical, timely, and engaging for a majority of diverse students.

Impediments To (Meaningful) Faculty Instructional Data-use Practices

Many of the summative and formative data types we heard about were consistent with Bouwma-Gearhart's (2021) and Hora et al.'s (2017) research with postsecondary STEM faculty. These researchers, too, found a diverse repertoire of practices used to measure student learning to inform their teaching. They, too, found that most faculty relied predominantly on summative and largely quantitative forms of data to inform teachings. Some faculty also relied heavily on formative and qualitative forms. Also consistent with the findings of Bouwma-Gearhart, Hora, and colleagues were the constraints that faculty identified as limiting their instructional data-use practices. These impediments included a perceived lack of time needed to implement instructional data-use practices, standardization of course content that restricted the types of practices used, and departmental structures that determined some types of practices. Like Bouwma-Gearhart, Hora, and colleagues' research, ours suggested that many STEM faculty may generally not feel prepared or empowered to effectively utilize diverse forms of instructional data to inform their teaching practice. Survey data that helped to motivate this study (detailed in the methodology section of this paper) pointed to a general lack of confidence and competence in collecting and using instructional data by faculty. Our study confirms this, mainly around qualitative and formative types of data.

Our faculty participants noted several nuances around the impediments to their instruction data-use practices. Specifically, time constraints revolved around certain types of formative assessments (e.g., journaling, group exercises), especially in large classes. Although faculty acknowledged that these formative assessments were valuable and even necessary, they were not always implemented. In part, faculty felt pressed to cover content, which suggests a perception that certain types of instructional data-use practices (e.g., formative) were somehow outside regular teaching norms and therefore needed to be added or fit into the class.

Notable too were mathematics instructors' laments of the "standardization" of course content. This usually indicated departmental requirements for common exams and grading policies. In some cases, this indicated large introductory courses that were taught by multiple faculty. These departmental structures suggested that faculty were not empowered to gather, analyze, and use instructional data to meaningfully inform their specific teaching-related questions and practices or to help students reflect on their learning achievements, a reality hinted at elsewhere in the literature (e.g., Hora & Holden, 2013, Hora et al., 2017).

Those faculty stating a lack of confidence and competence in collecting and using instructional data admitted it was the weakest part of their teaching. Faculty understood the importance of using instructional-data use practices to assess student learning, but they struggled with responding to data in their teaching practices. One faculty, additionally, was uncomfortable with their colleagues finding out about what they did to assess student learning. They perceived pushback from colleagues, partially based on their perception of being seen as an outsider in the field per their gender.

Attending to faculty comfort and norms with instructional data-use practices is one step in promoting faculty engagement in this research-confirmed practice to improve teaching. Interestingly, in comparison to Bouwma-Gearhart, Hora, and colleagues' study, faculty in our study were all involved in teaching improvement initiative activities and had largely been involved in multiple teaching improvement initiatives in their past. Arguably we might assume these STEM faculty are the most confident and competent (when compared to peers not engaging in such initiatives) in gathering, analyzing, and responding to data. Limited research points to STEM faculty members' participation in teaching professional development opportunities as predicted by their previous participation, as long as past opportunities were meaningful; in essence, those involved in improvement initiatives should be some of the most aware and practiced in implementing research-based teaching practices

(Bouwma-Gearhart, 2008, 2012). If this rationale is correct, and arguably we are in need of more research to confirm this, it points to multiple implications, namely that 1) many (most?) initiatives still do not focus on instructional data-use practices, and/or 2) such initiatives are not especially fruitful in expanding faculty practice around instructional data-use. Either reality presents implications for department leaders and professional development experts who aspire to support faculty development towards improvements to their teaching and, ultimately, student success.

Supports of Faculty Data-Use Practices

Faculty claimed multiple affordances for their instructional data-use practices that informed their decisions related to their teaching. Most faculty pointed to data they collected that provided insight around their teaching as data types and means that were norms for them as practitioners within their larger departments and organizations. Most faculty and departments privileged traditional types of student learning data such as exams and written assignments. Nevertheless, faculty also claimed they used other data to inform their teaching and students' learning, not traditional assessments. Several faculty claimed narrative and verbal forms, as discussed earlier, provided them novel and timely data to assess student learning and allowed them opportunities to interact and respond to students. However, most faculty still relied primarily on traditional methods, like exams, to gather quantitative data to inform their teaching. Faculty did seek different and more nuanced information, largely qualitative and formative, and several faculty tried to help students feel more comfortable and relaxed in demonstrating what they had learned. Learning and teaching assistants were another affordances that a few faculty used to gather data on students' achievements. Those faculty described developing a learning assistant program made up of former students who provided feedback on what was working or not related to the courses and students' understanding of concepts and content.

We found instructional technology afforded most faculty multiple instructional data-use practices by providing them with opportunities to collect and use data in different ways, such as clickers, online homework, adaptive learning tools, and other uses. Faculty who incorporated instructional technology tools in collecting student learning data were more likely to collect formative types of data. Having relatively easy access to large amounts of formative data encouraged faculty to collect this type of data more often and make more immediate or next-class-meeting changes to what content faculty would teach and what teaching strategies they would use. Instructional technology eased the burden of collecting, especially in large classes. In some cases, this allowed instructors to share student learning data with their students more readily. Faculty also used instructional technologies to assess trends in different groups of students, suggesting that some faculty intentionally recognize and attend to achievement gaps. In short, faculty who used instructional technology to collect data, largely formative, indicated they modified their instructional practices more often and quickly than those who collected data in other ways. Furthermore, they were more likely to engage students in reflecting on their learning. We think this finding is important because it adds to our understanding of how faculty perceive the instructional technology often, though not always, at their disposal, technologies that are often pointed to as allowing educators' data-based decision-making. Indeed, the faculty we spoke to claimed instructional technologies afforded them collecting different kinds of data and the ability to assess trends in student learning in a timely manner. Our research somewhat confirms the exploratory research of Hora and Holden (2013) on the role of instructional technology in STEM faculty's practices and backs their assertion that understandings around faculty practice are needed to design more locally tuned interventions, and that faculty must see the technology as salient to their practice. Based on our more nuanced findings regarding faculty's use of instructional technology, we recommend those who have responsibility for adopting and implementing instruction technology consider that faculty use instructional technology for multiple reasons and in multiple ways. Thus, including faculty in the decision-making process can result in more faculty adopting and using it.

Engaging Students in Reflecting on Their Learning

Our findings suggest that faculty were mixed in their practice of engaging students in reflecting on their learning data. Those faculty who did indicate they implemented these practices described activities where students reflected on their overall performance in class, such as open-ended questions that were added to daily in-class or homework assignments. Some faculty asked students through journaling activities to talk about their use of study techniques that may or may not be helping them. Again, these findings are promising, based on other research confirming structured and unstructured activities such as engaging students in journaling and open-ended questions that asked students to write about what they were learning or having difficulty with. These are effective strategies for promoting students' reflection on and understanding about their learning (Ryan & Ryan, 2015; Taras, 2002).

Still, a majority of faculty indicated they were not intentionally engaging their students in reflecting on their learning. Faculty described doing this least so with students in their lower-division courses, primarily based on the perception that students lacked the ability to meaningful reflect to the degree that could upper-division students. These faculty claims seem to suggest their assumptions that students have to achieve a certain level of cognitive development and/or understanding in a discipline before they can engage in reflecting on their learning. This may also suggest a faculty perception that students acquire reflection skills through means other than activities that are directed by themselves as their course faculty. Such assumptions may very well be unfounded (Sadler, 2010). Regardless, such thinking shifts the responsibility for student learning entirely to students' shoulders and suggests that faculty bear little responsibility for helping students be reflective learners. We assert that faculty need to provide opportunities for students to reflect on their learning in order for the student to gain an understanding of the particular aspects of their work that they need to attend to in order to be more successful. Professional developers and leaders can help by providing examples of practices that can be incorporated into classroom activities effectively and that engage students in meaningful reflection on their learning.

Further Recommendations

Throughout our above detailing of findings concerning STEM faculty instructional data-use practices, we have noted some recommendations for faculty leaders, professional development experts, and faculty themselves to design initiatives that support faculty practices that improve teaching and student learning.

Largely, these are towards what we see as the main goal of our study, that is to build from what we know to be working, around important faculty realities and needs towards improving the frequency and efficacy of instructional data-use practices, including faculty engaging students in more meaningful reflections on their learning. Here we detail recommendations more by main theme and stakeholder group.

- Faculty leaders and professional development experts must foster *ongoing and targeted professional development activities* that support faculty toward improving their instructional data-use practices based on best practice research. Professional development activities can elicit perceptions and experiences that will help faculty see which instructional data-use practices afford them the greatest potential for analyzing instructional data that improve their teaching practices and student learning.

- Faculty leaders and faculty must *commit to innovating and developing their use of instructional data-use practices* by recognizing that research-based instructional data-use practices can inform their teaching and improve student learning. Faculty are encouraged to explore the potential for collecting more formative data and finding efficient ways to gather and use it in timely and relevant ways to inform their teaching and students' learning.

- Faculty must *recognize the shared responsibility* for providing students the opportunity to reflect on and improve their learning. Fostering students' ability to reflect on their learning has implications for students and faculty through increased learning and achievement for students and data that inform adjustments to teaching that can enhance student learning.

- Faculty are encouraged to *take advantage of instructional technologies* available to them to enhance the gathering, analysis, and response to instructional data. Increasing faculty competence in collecting and responding to data that involves instructional technologies is critical. Faculty leaders and professional development experts must guard against mandating technology that is not perceived as relevant and usable.
- Faculty leaders and faculty are encouraged to *reevaluate curricular content development and processes* that may stifle faculty instructional data-use practices and explore changes to policies and norms that promote more research-based instructional data-use practices.

Understanding faculty perceptions about instructional data-use practices can further support professional development activities that help faculty understand their use and beliefs about effective instructional data-use practices. We know that faculty perceptions and practices are based on their previous experience, perceptions, attitudes, and practices (Pajares, 1992). Any targeted professional development strategies that better support faculty must account for these realities. Indeed, faculty are much more likely to feel competent in using instructional data when they have a say in their experiences with the instructional tools and the teaching practices that effectively incorporate instructional data in daily processes (Hora & Holden, 2013). Professional development activities must invest faculty in the data-driven decision-making processes that make sense.

Future Research

Faculty instructional data-use practices, and the perceptions and realities that root them, can inform future research and interventions towards postsecondary STEM education improvements, ultimately towards enhanced success for diverse student populations. Our study is one step in this direction, yet there is still much to discover. Future research could explore more nuanced faculty perceptions and practices across disciplines, including across STEM. Indeed, STEM is not a monolith (Reinholz et al., 2019), and we need to explore differences that may exist for faculty and their organizations that may rely on different ways of knowing, cultures, and structures. For instance, are there instructional data-use practices that faculty find particularly effective in certain disciplines? How can departments and institutions support effective instructional data-use practices and still maintain requirements mandated across their specific stakeholders (e.g., faculty and students, accreditation bodies, industry)?

More research is also needed that further explores the impact of instructional technologies on actual faculty practice. For instance, how do faculty incorporate these tools, and what intervention strategies are most helpful in supporting their actual use? What technologies generate the most meaningful and efficient data for faculty to inform their teaching? How can department leaders and professional development experts support faculty in engaging students in reflecting on their learning? What professional development activities increase faculty confidence and competence and actual use of instructional data to inform practice? What data provide the most reliable and valid read for faculty across numerous problems of practice? Future research could also explore the most effective and efficient ways that faculty can engage students in reflecting on their learning. What else inhibits faculty from engaging students in reflecting on their learning, given the benefits for students? What data are most effective in providing students accurate and discipline-aligned insight for students? What practices best inspire students to accept their agency in assessing and ensuring their learning across STEM disciplines?

Conclusion

Faculty and student interactions in learning environments are complex. Given a relatively typical target of postsecondary education improvement interventions, we are especially in need of understanding how and why STEM faculty gather, analyze, and respond to instructional data. This study adds to the limited research that examines STEM faculty's instructional data-use practices. As research has confirmed, innovation and changes to instructional practices can be slow and challenging. However, we contend that this study indicates some research-confirmed instruction data-use practices of STEM faculty that inform their teaching. STEM faculty now, more than ever, may be attempting more effective and inclusive strategies to assess their students' learning, reflecting a diverse student population who has not traditionally experienced sustained success in STEM files. Faculty are recognizing and incorporating more formative types of data and rethinking how they are using summative data to determine student learning and grades. Faculty may be incorporating more instruction technology that provides them with more strategic ways to collect student learning data and to respond in real-time teaching. We suggest that departmental leaders, administrators, and professional development experts are critical in the continued support of faculty in their development of effective data-use practices that make sense per their and their students' realities. We see a need for more research that explores these realities to strengthen and expand support efforts.

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Appendix A

Interview Protocol

Faculty Interview Questions

1. I'd like to know more about your position at [Name of University].

a. Specifically: What is your official title?

b. What classes did you teach this academic year, 2016-2017?

c. Have your teaching responsibilities changed since last interviewed for this project?

d. How much autonomy do you have over what and how you teach?

2. Do you interact regularly with any others concerning issues of teaching and learning?

a. [If yes], please provide detail regarding those interactions: including

i. who? 1. Are these people in your discipline/department/program?

ii. how often?

iii. regarding what specifically?

b. What encourages or discourages these interactions?

c. Has [Name of Initiative] influenced these interactions in any way?

3. I'd like to hear about your engagement with the [Name of Initiative] project. Specifically:

a. What has been your affiliation with the [Name of Initiative] project? What activities have you attended?

b. Have you noted any impact of [Name of Initiative] on you?

c. Have you noted any impact of [Name of Initiative] on others?

4. Please describe any evolution in your teaching practices over the last couple of years that you can attribute to improvement initiatives or professional development activities. [If not mentioned, probe for specifics via questions a and b.]

a. Have any university or departmental initiatives or teaching professional development opportunities impacted this evolution?

b. Has [Name of Initiative] influenced your evolution in any way?

5. I'd like to hear about your assessment practices while teaching.

a. To what extent do you collect data/information about student learning?

b. Are you teaching practices informed by data/information about student learning?

c. Are there means in the classes/courses that you teach for students to reflect on their own learning data? [If yes], Can you detail these processes?

6. Describe a successful student in the courses or programs in which you teach.

a. Overall, what do you consider as the most effective teaching strategies towards developing these things?

b. To what extent do you employ these teaching strategies?

7. A goal of the [Name of Initiative] project is widespread improvement to teaching practices and learning outcomes in undergraduate STEM education across [Name of University]. Our general strategy is promoting educators' learning about evidence-based instructional practices via interactions with other educators.

a. What do you think about this goal and strategy? Do you have any evidence that widespread improvement to teaching practices and learning outcomes in undergraduate STEM education have happened in the last couple of years at [name of university]

b. Can you attribute any changes to the [Name of Initiative] project?

c. Have you noted any affordances and barriers towards widespread improvement to teaching practices and learning outcomes in undergraduate STEM education, that can inform efforts like [Name of Initiative]?

8. A specific goal of the [Name of Initiative] project was to promote active learning and cooperative learning, especially in large, introductory, gateway courses. We define active learning and cooperative learning as X [definitions provided to interview on a handout]

a. What do you think about this goal and strategy?

b. Do you have any evidence that promote active learning and cooperative learning has increased in large, introductory, gateway courses in the last couple of years at [name of university?

c. [If so] Can you attribute any changes to the [Name of Initiative] project?

d. Have you noted any affordances and barriers towards active learning and cooperative learning has increased in large, introductory, gateway courses, that can inform efforts like [Name of Initiative].

Appendix B

Codes and Descriptions

*Types of Student Learning Data: Sample of Codes and Definitions**

Code Names	Code Descriptions/Definitions
Formative Data Assessment Strategies	Quantitative and qualitative data about student learning collected via assessments generally during class (but not always) with the purpose of assessing students ongoing learning and to adjust teaching practices in real time
• Narrative Data Practices	Mostly qualitative methods of collecting student learning data such as exit slips or "muddy point" exercises to inform decisions about teaching practices.
• Numeric Data Practices	Mostly quantitative methods of collecting student learning data such as clickers, online pre-post quizzes or homework to inform decisions about teaching practices.
Summative Data Assessment Strategies	Formal data assessment strategy to collect data via exams, quizzes, and written work such as essays. Analyzed at the end of a section or term to guide decisions about grading and teaching practices/course design for the next term.
Verbal Data Practices	Verbal data collected by the instructor either through talking with students or talking with teaching assistants or other instructors.

*Codes and definitions interpreted from Bouwma-Gearhart (2020)

Chapter 5 - Conclusion

STEM faculty occupy a unique and potentially powerful position to influence students' success and persevere in their fields. Insights into how faculty approach teaching, how they develop curriculum, why they choose particular teaching practices, how they perceive students, and how they inform and improve their teaching practices are relevant for anyone encouraging their curricular and instructional improvements. This dissertation reported on studies around these aspects of faculty teaching practice across four different postsecondary institutions, based on the perspectives and realities of 38 postsecondary faculty and leaders. Findings from the three manuscripts presented in this dissertation offer novel insights concerning how faculty experience and develop transdisciplinary curriculum, how faculty perceive notions of successful students and their teaching practices that support them, and how faculty instructional data-use practices inform their teaching practices, student learning, and student reflection on their learning. In this conclusion, I detail the findings of each manuscript quickly in turn. I then reflect across the manuscripts to discuss overarching themes that emerged findings, and recommendations I think pertinent for various stakeholders (i.e., department leaders, administrators, professional development experts, and others) towards postsecondary STEM education improvement efforts.

Overview of Manuscripts

The first manuscript recognizes the growing importance of engaging postsecondary students in experiences that can heighten their ability to help address complex socioscientific problems. I explored the development of a transdisciplinary curriculum by 12 faculty and seven project leaders that would require students to integrate and synthesize knowledge, skills, and ways of thinking across typical disciplinary boundaries of natural and social sciences. This research was motivated by research that indicated that faculty co-creating a transdisciplinary curriculum is novel and would be challenging, given faculty members' professional rooting within disciplines and the academy's structures and practice-norms. I sought to provide insight via one interdisciplinary faculty attempt, exploring the affordances and constraints that faculty encountered. Faculty were motivated by their professional development needs, including an interest in creating curricula around sustainability issues, a desire for improved teaching practices, and their seeking to develop curricula that would enhance student learning. I found that faculty experienced tensions related to navigating disciplinary norms, practices, and language, concerns around the suitability of transdisciplinary curricula in their courses, and their confidence in teaching and collaborating across disciplines. Project leaders were influential facilitators and co-developers and were deemed essential to the curriculum development's success. I discussed implications for faculty, academic leaders, administrators, and other stakeholders interested in future efforts that involve faculty working across disciplines to develop transdisciplinary curricula to meet societal needs. These included helping to secure resources related to faculty time and stipends that allow faculty to work on these projects, communicating the benefits of faculty working across disciplinary boundaries that can strengthen disciplinary content and relevance, and changing policies and practices that might stifle faculty efforts to create transdisciplinary curriculum.

The second manuscript recognized the importance of faculty perspectives related to their student's success and the teaching practices they employed. I provided STEM faculty perspectives, including a range of characteristics and factors indicative and predictive of student success. STEM faculty notions of successful students were predominantly described as student engagement, behavioral, cognitive, or affective engagement. Faculty sought to engage students in multiple ways through their teaching strategies. Using interviews from 19 STEM faculty, I explored concerns related to structures, such as meritocratic processes and unexamined and unspoken expectations that may position some underrepresented groups (i.e., women, racial/ethnic, other marginalized groups) to be less successful. I found that some faculty still claimed to continue to rely primarily on lecturing as a strategy, without obvious incorporation of evidence-based instructional practices, especially in lower-division introductory courses, where research suggests using evidence-based strategies is most effective and needed. I discussed implications for my findings and suggested broader opportunities for departments to tap into faculty members' espoused commitments to helping their students succeed and explore more evidence-based instructional practices that continue to foster the kinds of characteristics that faculty value most in their students. I discuss implications for faculty engagement in improvement initiatives that encourage reflective activities designed to investigate their students' perceptions and teaching practices, including building more obvious networks and support strategies with student services personnel to broaden faculty knowledge that supports student success.

The third manuscript recognizes the complexities of STEM faculty members' instructional data-use practices. I explore the types of instructional data-use practices that faculty claimed they used to inform their teaching practices and student learning. These included summative types of data such as exams and quizzes, which faculty perceived as practical measurements of student learning and grades. Faculty also collected data through various formative or qualitative data-use practices such as curricular artifacts (e.g., journaling) or verbal data (e.g., talking with students or teaching assistants). The faculty also discussed affordances and constraints for these practices, including available instructional technologies. As well, I explored how faculty engaged students (or not) in reflection around their learning data. I confirmed the limited research of others, which found faculty used various instructional data-use practices, including collecting formative and summative data. I also confirmed the limited research of others around faculty perceptions of barriers to their instructional data-use practices, including lack of time, standardized curriculum, predetermined assessments, and a perceived lack of confidence and competence in their instructional data-use practices. I also discovered novel findings, including faculty notions of instructional technologies they claimed allowed them more timely and complete data to respond to more immediately in practice. Faculty who used adaptive learning technologies also claimed it helped them collect more nuanced data on achievement trends for different groups of students. Although all faculty used summative data (i.e., exams, written assignments), several faculty described less reliance on these typically used data as indicators of student learning; these faculty, instead, claimed to use other practices, such as student performance during group work and informal discussions with students, as formative data to better measure student learning.

In some cases, faculty claimed these practices as lower stakes and lower stress for students. Faculty were mixed in their practice of engaging students in reflecting on their learning data, with more than half indicating they did not engage students in reflecting on their learning. I found these practices were generally described as activities in which students were asked to reflect on their overall performance in class and how their use of study techniques may (or not) be helping them, as opposed to just looking at an exam score. I discussed implications for departmental and institutional leaders, faculty leaders, professional developers, and for faculty themselves, including providing faculty with needed support and encouragement to take advantage of instructional technology, more effective means of collecting formative data, and a reevaluation of departmental and program requirements that may stifle instructional data-use practices.

Overarching Themes

In response to concerns around postsecondary students' success in the STEM disciplines, higher education institutions have promoted opportunities for faculty to engage in efforts to improve teaching and learning that result in greater success for students (Austin, 2011), particularly students from underrepresented populations who have not achieved equitable success in many STEM disciplines (Johnson, 2007; Shapiro & Sax, 2011; Varelas et al., 2015). These opportunities have been slow and challenging to implement (Bouwma-Gearhart, 2012; Henderson et al., 2011). I argue that there is a need to better explore faculty practices and other realities, to inform the design and implementation of future efforts.

Towards this and my future research and career goals, when I look across the manuscripts, two overarching themes emerge. I suggest these themes provide a potential framework for recommendations that department leaders, administrators, and others concerned with faculty development need to consider when engaging and supporting faculty efforts to improve their practice. The first theme centers on faculty *commitment and motivation.* The second theme addresses *departmental and institutional structures that influence faculty activities* and teaching practices. I discuss these themes before highlighting recommendations for stakeholders to better support faculty work, innovation, and improvements.

Commitment and Motivation

Looking across the three manuscripts, I am struck by the *commitment and motivation* faculty had toward providing their students with relevant and engaging educational experiences toward their success. For instance, in the study detailed in manuscript one, I found faculty were motivated to participate in developing a transdisciplinary curriculum because they thought it would benefit their students, making the curriculum more relevant, timely, and interesting for students. Faculty were excited to participate because they recognized the need to engage their students in curricula that provided students with diverse perspectives on global and societal problems, thus preparing students with critical thinking and problem-solving skills. They were also committed to learning from their colleagues to enhance their practices. Further, faculty who had taught the curriculum or thought about how they were going to incorporate the curriculum in their courses found that they were making other innovations and changes in their courses. They were motivated to redesign other parts of their course after creating the transdisciplinary curriculum. For example, one economics faculty redesigned her entire economics course to be problem-based rather than topic-based. She said her students were engaged and excited about what they were learning. Her commitment and motivation to provide a relevant curriculum for her students and the opportunity to work in the initiative made a significant difference in how she thought about her teaching and her interaction with her students.

Although faculty commitment and motivation were less obvious in the studies in manuscripts two and three, I found that faculty consistently mentioned various instructional practices they claimed cultivated student engagement and student success. In the study in manuscript two, I found that faculty were committed to engaging students in multiple ways to foster and cultivate their success. Another indicator was the recognition by several faculty that students might experience STEM classrooms differently. This awareness was apparent in their motivation to talk about what they were doing to foster student success. I recommend tapping into faculty members' espoused commitment to helping their students succeed, which can open the door for faculty to explore more evidence-based instructional practices that foster the kinds of characteristics that faculty actually value most in their students and see as critical markers of success. In the study in manuscript three, faculty describe several novel instructional data-use practices that faculty designed and were motivated to implement because they thought it supported diverse student groups. For instance, when they minimized the influence of traditional exams as a sole determinant of grades because they realized that exams might not demonstrate many students learning and achievement. This novel insight by faculty related to supporting underrepresented students in STEM demonstrated faculty commitment and motivation to foster student learning and success.

A theme of faculty commitment and motivation is worth considering, in light of the many calls for faculty to improve their practices, and the challenges and slow pace of many improvement efforts, and the barriers that still stand in the way of student's success for underserved and underrepresented groups in STEM disciplines. I advocate for leveraging faculty's commitment and motivation to encourage participation in improvement initiatives. There is still more to be done to encourage faculty to reflect on and examine their role in fostering student success. However, faculty commitment and motivation for supporting students can act as powerful levers for engaging faculty in participating in professional development initiatives. Findings from the three manuscripts highlight the recognition by some faculty that not all students bring the same backgrounds and experiences to STEM classrooms, thus their motivation to incorporate more research-based practices. Indeed, I recommend future initiatives highlight the benefits to diverse student populations that faculty may realize via their involvement. I recommend future initiatives evaluate the benefits that students may receive due to faculty engagement in improvement initiatives that target faculty commitment and motivation.

Departmental Structures Influence Faculty Activities and Teaching Practices

Faculty do not work in isolation, and improvement efforts have to account for the many levels that constitute education environments. Therefore, looking across studies in each of the manuscripts, I am additionally struck by the intersection of complex phenomena inherent in higher education systems, specifically how departmental and institutional structures influence faculty innovation and improvement efforts. My research confirmed that faculty work in complex environments that impact faculty practice, commitments, and decisions. For instance, in the study detailed in manuscript one, I found that faculty who worked in what they perceived to be collaborative and innovative departments perceived developing transdisciplinary curriculum as an activity that fits their department's goals to create curricula that incorporated more than one discipline. Indeed, they were the ones least concerned about how they would collaborate with other faculty or fit the new transdisciplinary curriculum into their courses. Their departmental policies or norms seemed partially structured, at least, to influence their cross-disciplinary collaborations. This support was not the case for other faculty, who worked in institutions that seemed more siloed and compartmentalized by disciplines. These faculty faced more pressure from other faculty and department leaders to devote their time to their disciplinary work, which influenced faculty's potential participation and left some faculty feeling they needed to volunteer their time if they wanted to do something innovative with those outside of their discipline/department. Even those faculty who saw developing transdisciplinary curriculum as the desired goal of their department still discussed the influences they perceived regarding such policies.

These influences were related to time devoted to these kinds of projects and workload and promotion and tenure considerations that did not always incentivize the types of across-disciplinary work they were doing.

I also discussed department structures that influenced faculty innovation in the studies detailed in manuscripts two and three. For instance, in the study described in manuscript two, faculty structured their courses differently depending on students' perceived abilities and preparedness and in faculty's felt need to cover the content. Faculty who perceived students lacking in academic preparedness were more likely to use lecture-based strategies over evidence-based instructional strategies. Furthermore, faculty perceptions of their students influenced their interactions which may also reveal hidden rules and departmental norms that are not recognized by students who are newer to a system or less knowledgeable or influential within it.

In the study detailed in manuscript three, faculty actions around their instructional data-use practices were influenced by their department's priorities, which largely constrained their activities, including the standardization of curriculum or the expectation that summative evaluations should remain the primary determinant of student grades. These priorities influenced faculty's limited use of formative instructional data-use practices, which might serve as more timely and meaningful feedback for faculty in terms of potential revisions to practice and enhanced student success. In addition, some faculty perceived gender bias from their colleagues, which influenced their interactions with other faculty within their departments.

Recommendations for Future Improvement Efforts

I hope that this dissertation and findings within can serve to inform the work of faculty and department leaders, professional development experts, and administrators who can create and support professional development opportunities related to faculty improvement efforts. These stem from the two themes noted above. We must recognize the realities of faculty work in higher education environments. Faculty operate in complex situations and have competing interests that involve time, effort, and resources. External forces influence faculty decisions related to how much time and energy they devote to teaching and improving their practices. It cannot be overstated that even faculty who want to improve their teaching and their students' success (learning and persistence) may find it challenging to devote the time and energy to activities that can help them do so. Faculty agency to engage in improvements, somewhat regardless of their commitments and motivations to do so, are constrained by the structures that exist. These sometimes competing interests have to be weighed in light of faculty and students' benefits (e.g., life outside academe, stakeholder demands). Other constraints can be lessened, omitted, or modified in influence, such as departmental and institutional norms and processes that may make innovation and improvement efforts difficult. And other factors might be used as levers to better attract and support faculty in improvement activities.

Research confirms that faculty need the time and resources to innovate and improve their practices, in part through their interactions with other faculty. Faculty efforts to enhance their practice require faculty to inquire and reflect about their problems of practice and possible remedies that would help them achieve their instructional goals. Indeed, I recommend that department leaders, faculty development experts, and administrators provide not only the time, space, and sustained resources for faculty to engage in exploration, collaboration, and development efforts that realize improvements but also create the structures (i.e., policies and opportunities) that support faculty involvement.

Given these realities identified within the independent manuscripts and the themes above, I recommend:

1. *Fostering more faculty members' understanding of the importance of evidence-based practices* as detailed in this dissertation, including those practices that promote students' engagement and reflections on their learning.

2. *Providing faculty with intentional opportunities* that recognize the complex factors that faculty navigate in their work and that mitigate competing ones.

3. *Creating opportunities for faculty to collaborate with other faculty* (including in other departments/disciplines) to learn from one another, including expert leaders.

4. *Recognizing faculty desires and the time and space* needed to engage in teaching-improvement activities.

5. *Allocating institutional resources*, including stipends and rewards, and course releases that can serve to mitigate other faculty concerns in the

way of their improvement efforts and demonstrate a commitment to faculty in their improvement efforts.

6. *Empowering faculty leaders who possess relevant expertise* to facilitate and guide improvement efforts and act as mentors and co-developers. These leaders can be instrumental in recruiting and supporting faculty involvement.

7. *Developing and supporting the implementation of instructional technologies* that support faculty teaching and learning efforts to make the technologies relevant and based on faculty's perceived problems of practice. Faculty must also have professional development in using instructional technology effectively and learning what appears to be working for them, with plans for modification of technologies when less effective.

8. *Developing policies and practices that incentivize and reward faculty* for engaging in improvement efforts. Policies should build on faculty motivations, commitments, and felt needs, to attract and secure their participation in teaching-related activities, including improvement initiatives. In addition, policies should specifically address promotion and tenure considerations, additional stipends and release time, and access to professional development activities that are sustained over time.

9. *Providing training for administrators and other leaders* in creating optimal environments for faculty development and innovation. This

training should include understanding relevant policies and cultures and how to lead organizational change around these. In addition, administrators and leaders need professional development that helps them learn and commit to uncovering faculty needs and realities and designing and implementing relevant professional development in light of this.

10. *Integrating the work of STEM departments* with other professional development efforts across the campus can synergize teaching improvement efforts that increase efficiencies and reduce burdens for faculty and leaders. This integration can also mean connecting with centers for teaching and learning innovation to share resources.

Professional Direction Inspired by Dissertation

The work outlined in this dissertation is important to me personally and professionally. I brought my practical experiences as a faculty member for 20 years in a community college, a department chair, an associate vice president of instruction, and a national organization's vice president to my doctoral research. These experiences provided me foundations to hypothesize and understand faculty realities influencing teaching and teaching improvements. They provided me with basic understandings that I built on per my coursework and other experiences as a doctoral student of the research that has been done, and the research still needs to continue in promoting effective instructional strategies that are equitable and inclusive for students.

Per my doctoral research, I now bring greater understanding afforded me per my doctoral work to my goal to work as a postsecondary administrator. This role will allow me the greatest opportunity to put my experiences and my research into practice, and that provides postsecondary faculty, especially in STEM fields, with the support they need to engage their students and improve their teaching practices. Faculty are working in complex environments that afford and constrain efforts to improve research confirmed practices. The best-case scenario for faculty is to engage in sustained efforts that involve new technologies, include time, resources, and expertise that support innovation, and challenge conceptions of student success, particularly for underserved and underrepresented populations. As a researcher and a practitioner, I will continue to communicate my research and related practices to the larger community to encourage and support other administrators and faculty in their work.

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