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How facilitating K–12 professional development shapes science faculty's instructional change

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Abstract

Although the use of active learning pedagogies in college science courses has been demonstrated to improve student learning and engagement, lecture-based methods still feature predominantly across university courses. Often lacking meaningful opportunities to learn about and test out new pedagogies, faculty have been slow to adopt and enact new teaching practices. Partnerships in which faculty facilitate teacher professional development may provide an important space for faculty learning and innovation related to college instruction. There is a large body of research examining the impact of such partnerships on teacher instructional change; however, few studies consider the impact of these programs on the instructional practices of science faculty. Moreover, existing studies lack theoretical frames to elucidate the various processes that shape faculty adoption of new teaching practices. This qualitative study examines the processes by which science faculty reshape their pedagogical practices through facilitating professional development for K–12 teachers, and how individual characteristics, social interactions, and organizational contexts influence their choices. We use a theoretical framework that affords an understanding of the iterative process and multiple factors that influence shifts in instructional practice. Implications of findings for grant-writing and professional development that foster

opportunities for relationship building and learning among faculty and teachers are discussed.

KEYWORDS
faculty instructional change, higher education, professional development

1 | INTRODUCTION

Shifting of faculty teaching practices at colleges and universities away from lecture-based instruction toward more student-centered, active learning pedagogies has been shown to improve student learning and engagement, particularly in high-enrollment undergraduate science courses (e.g., Freeman et al., 2014; Haak et al., 2011; Inouye et al., 2017). Yet, the majority of university courses are still taught using predominantly traditional lecture-based methods (Eagan et al., 2014; Stains et al., 2018). Numerous factors influence the slow adoption of active learning pedagogies by college faculty, including limited time and resources to experiment with and implement new approaches and a lack of incentives to innovate in teaching (Anderson et al., 2011; Brownell & Tanner, 2012; Sunal et al., 2001). Without meaningful opportunities to learn about and test out active learning pedagogies, it is unlikely that many science faculty will make significant changes to their traditional teaching practice.

School–university partnerships, in which higher education science faculty[1] facilitate professional development (PD) for K–12 teachers, can serve as an important space for innovation in science teaching for *both* teachers and faculty. Research indicates that participation in science PD led by university faculty supports content gains among K–12 teachers, spurs improvements in K–12 science teaching, and increases teacher confidence with science instruction (Bae et al., 2016a; Tanner et al., 2003; Zhang et al., 2011). Yet, few studies have examined the impact of facilitating teacher PD on the instructional practices of university faculty (Knowlton et al., 2015; Zhang et al., 2011).

Participation in teacher PD may provide an important but overlooked context in which faculty engage with like-minded colleagues, teachers, and pedagogical experts in a community with a common teaching-focused purpose, that in turn, may encourage faculty to reflect on their own teaching practices. However, the existing studies in this area are atheoretical (Knowlton et al., 2015; Thompson et al., 2002; Zhang et al., 2011), or predicated on frameworks that describe either categories of faculty change (e.g., research, teaching) or external influences on change (e.g., tenure and promotion; Pomeroy et al., 2011; Pomeroy, 2010). The existing literature does not provide a theoretical explanation of the iterative change processes that occur as faculty participate in school partnership projects and translate what they learn into their college classrooms. To develop a theoretically grounded understanding of faculty change in this unique professional learning situation, we applied an existing, relevant model and operationalize the model to understand faculty changes as they facilitate PD.

The purpose of this study is to examine the processes by which science faculty reshape their college teaching practices as a function of facilitating PD, and the ways that individual characteristics, social interactions, and institutional contexts can influence their pedagogical choices. We conduct this study using a theoretical model that affords an understanding of the processes that shape instructional change (The Interconnected Model of Professional Growth in an Organizational Context; Clarke & Hollingsworth, 2002; Hayes et al., 2019). Gaining a better understanding of such processes will support grant-writing and PD planning efforts that focus on intentionally fostering reciprocal learning opportunities among faculty and teachers, providing a potentially fruitful avenue to support faculty in shifting their instruction towards active, student-centered approaches in higher education science courses. Our study is guided by the following research questions:

- What are the processes by which science faculty shift their pedagogical practices through participating in a school–university partnership?
- How do individual characteristics, social interactions, and organizational contexts shape science faculty shifts in instructional practice?

2 | LITERATURE REVIEW

2.1 | Instructional practices in undergraduate science courses

A significant body of research has developed in recent decades to explore how student-centered, active learning pedagogies support academic success and engagement in undergraduate science education (e.g., Deslauriers et al., 2011; Freeman et al., 2014; Haak et al., 2011). These approaches leverage students' prior knowledge and experiences, value collaborative learning structures, provide opportunities for constructing new knowledge, and encourage the transfer of knowledge to new situations and settings (e.g., Kober, 2015; National Research Council [NRC], 2012). We use the term "active learning" throughout the paper to refer to these instructional approaches.

As an illustration of the power of active learning, in their longitudinal study of introductory biology courses, Haak et al. (2011) compared student learning outcomes in traditional lecture courses versus those that incorporated active learning pedagogies, including peer instruction, student problem-solving during lectures, and peer review. They showed that, as compared to traditional lectures, active learning opportunities were associated with improved performance among all students in the courses as well as reductions in achievement gaps for students from disadvantaged backgrounds (Haak et al., 2011). Similarly, in a meta-analysis of 225 studies of student performance in undergraduate STEM courses, Freeman et al. (2014) reported that performance on examinations was significantly higher in courses that incorporated active learning into instruction, as measured through scores on examinations and standard concept inventories. These active pedagogical approaches are becoming more relevant as institutions of higher education increasingly focus on improving the academic success and retention of undergraduate science majors from historically underrepresented backgrounds (National Center for Education Statistics [NCES], 2019; Toven-Lindsey et al., 2015).

Additionally, studies show that students report higher engagement in science courses where they have the opportunity to participate in dialog with the instructor and their peers, and to connect their learning to real-world issues (e.g., Gasiewski et al., 2012; Inouye et al., 2017; Xu et al., 2018). These findings highlight the importance of shifting toward more active learning pedagogies and inclusive classroom practices that have been shown to improve learning outcomes and persistence in science majors for all students (e.g., Freeman et al., 2014; Gasiewski et al., 2012) and for underrepresented students, in particular (e.g., Haak et al., 2011).

2.2 | Shifting faculty teaching practices

Though these studies point to a growing interest in improving instructional practices, research indicates that changes in university science instruction have been limited. On the basis of a national survey of more than 16,000 teaching faculty, the Higher Education Research Institute reports that lecturing remains prevalent, with 50.6% of faculty reporting that they lecture extensively in all or most of their courses (Eagan et al., 2014). Similarly, in a study of more than 2,000 STEM classes across 25 institutions, Stains et al. (2018) found that 55% of the courses observed could be characterized as using didactic teaching style (e.g., lectures and demonstrations).

The relatively slow adoption of active learning strategies amongst science faculty has been attributed to a range of individual, social, and organizational factors (Gess-Newsome et al., 2003; Henderson et al., 2011; Lane et al., 2019). In regard to individual factors, faculty beliefs about teaching and their teaching experiences can

influence a faculty member's interest in professional learning (Michael, 2007). In a study of 86 instructors at two universities, Thadani et al. (2015) found that individuals who believed that teaching skills could be learned and improved upon were more likely to engage in collaborative faculty PD. Other studies show that discontent with one's teaching practice can serve as an impetus for seeking professional learning opportunities and support from colleagues (Bouwma-Gearhart, 2012; Gess-Newsome et al., 2003). Additionally, beliefs about student learning can influence faculty engagement with instructional reforms. For example, it is difficult to move toward an inquiry-based model of science instruction if an instructor holds a foundational belief that students are ill-prepared and incapable of mastering complex scientific phenomena (Gess-Newsome et al., 2003).

In terms of social factors, in recent years scholars have begun using social network analysis to better understand the ways that networks of relationships influence individuals' decision to engage in instructional reform efforts at institutions of higher education (Kezar, 2014; Lane et al., 2019). These studies have helped researchers understand the mechanisms by which instructional norms change, such as how new instructional practices are spread (Kezar, 2014). For example, in a study of full-time biology and chemistry faculty across three universities ($N = 132$), Lane et al. (2019) found evidence of peer influence on the use of evidence-based teaching practices. Additionally, the literature points to the important role of professional learning communities in supporting faculty in developing norms for innovative teaching (Shadle et al., 2017). Having the opportunity to iteratively try out new ideas and refine their teaching strategies, particularly in a low-risk and collaborative environment, can contribute to more meaningful shifts in a faculty member's knowledge and practice situated within this social and institutional context (Green et al., 2013; Lave & Wenger, 1991).

Organizational factors include institutional policies and structures that can influence the way faculty, particularly new instructors, approach their teaching practices (Birt et al., 2019; Henderson et al., 2011; Shadle et al., 2017). Brownell and Tanner (2012) argue that teaching is not a significant component of, and sometimes even in conflict with, scientists' professional identity. In addition, incentive structures in higher education tend to deprioritize innovations in teaching. Most graduate students in STEM fields have few opportunities to teach their own courses, and they often learn about teaching by watching their mentors use traditional, lecture-based approaches (Brownell & Tanner, 2012). Such incentive structures and lack of exposure may result in STEM graduates being socialized to believe that teaching has a lower status in their professional community compared to research (Thompson et al., 2002; Zhang et al., 2010). This socialization may play a role in the way science faculty approach their teaching practice and engagement in professional learning.

Despite the need for learning about teaching, faculty PD often consists of short-term programs that do not incorporate communities of practice whereby faculty can engage with colleagues on a regular basis to discuss ideas and challenges related to their instruction (Bouwma-Gearhart, 2012; Ebert-May et al., 2011; Furco & Moely, 2012). Anderson et al. (2011) advocate for numerous mechanisms to support science faculty in ongoing reflection and improvement of their teaching practices, including exposure to educational theories and active, inquiry-based pedagogies, time and institutional support to experiment with new teaching methods in specific contexts, and engagement in faculty communities of practice. In the following section, the potential of school–university partnerships for creating opportunities for science faculty to engage in such learning activities are reviewed.

2.3 | The potential of school–university partnerships

A largely unexplored space that may provide authentic opportunities for science faculty to improve their science instruction is by working with K–12 teachers, often referred to as a school–university partnership (e.g., Huziak-Clark et al., 2007). The term school–university partnership has been used to describe a wide range of partnership activities. Specifically, in the context of this study, we are referring to a multiyear project in which science faculty facilitate PD for K–12 science teachers. As common in most school–university PD models, science

faculty served as content experts to provide insights into the nature of scientific inquiry and enhance teachers' content knowledge (Tanner et al., 2003).

Such partnerships have been shown to support K–12 teacher content knowledge, self-efficacy, and use of inquiry-based pedagogies. For example, in a study of 41 middle and high school teachers who participated in PD led by university faculty, teachers advanced their science content knowledge regardless of their level of prior expertise (McConnell et al., 2013). Likewise, based on a study of 107 elementary and middle school teachers who participated in a science PD led by university faculty, Lakshmanan et al. (2011) reported that teachers showed significant growth in both self-efficacy and the extent to which they implemented inquiry-based instruction in their classrooms.

Despite a tremendous focus on teacher learning in such faculty-led PD, relatively few studies have examined the impacts of facilitating PD on the instructional practices of science faculty. Existing studies suggest that leading teacher PD can support science faculty in using inquiry practices (Knowlton et al., 2015; Zhang et al., 2011), applying new ways of explaining content (Olitsky, 2017; Thompson et al., 2002), designing activities for small group interactions, and considering students' prior knowledge (Pomeroy et al., 2011; Zhang et al., 2011). This study also suggests that faculty learning and instructional change is influenced by several individual and contextual factors. Individually, faculty who participate in such projects often demonstrate a concern for public education, motivation to support teacher learning, and a reflective attitude toward their own teaching (Pomeroy, 2010; Zhang et al., 2011). Contextually, as noted in a larger body of literature, this study shows the tenure and promotion process prominently affects faculty participation in K–12 PD and potential for shifting their own practice (Pomeroy, 2010; Zhang et al., 2010).

Preliminary work suggests that professional relationships and community may also influence the ways faculty learn about and take up new instructional practices. For example, Pomeroy (2010) noted that relationships with teachers provided a context within which faculty discussed and considered new instructional practices and that the opportunity to work closely with like-minded colleagues provided support as faculty grappled with pedagogical issues (Pomeroy, 2010). Yet, these studies are limited in number and do not account for the processes by which faculty explore and implement new practices in a theoretically grounded manner.

3 | THEORETICAL FRAMEWORK

To understand the ways in which facilitating teacher PD shapes faculty practice, we use a framework characterizing the processes by which teachers change their instructional practice, called the Interconnected Model of Professional Growth in an Organizational Context (PGOC model). This model was originally constructed by Clarke and Hollingsworth (2002), then adapted to account for organizational context by Hayes et al. (2019; Figure 1). Although we are studying faculty instructional change, this framework is appropriate as a starting point because it acknowledges that instructor change is an iterative process influenced by a variety of personal characteristics and contextual features.

As a foundation, the framework takes up Clarke and Hollingsworth's (2002) propositions that teacher learning and change is not a linear process (e.g., Desimone, 2009), but instead is a reflective and reflexive process that involves four domains: (a) The personal domain, which encompasses instructors' existing knowledge, beliefs, and values; (b) the external domain, a source of new ideas and information; (c) the domain of practice, the space in which instructors try out new ideas; and (d) the domain of consequence, which consists of relevant outcomes such as student learning. All four domains can be subject to change through reflection and enactment in an iterative way (Clarke & Hollingsworth, 2002), as demonstrated by the arrows in Figure 1.

The original Clarke and Hollingsworth model accounts for the ways that existing knowledge and beliefs, new information, and student reactions shape instructional change (Spillane et al., 2002). In the original model, Clarke and Hollingsworth also note that the changing environment plays a substantive role in whether and how teachers

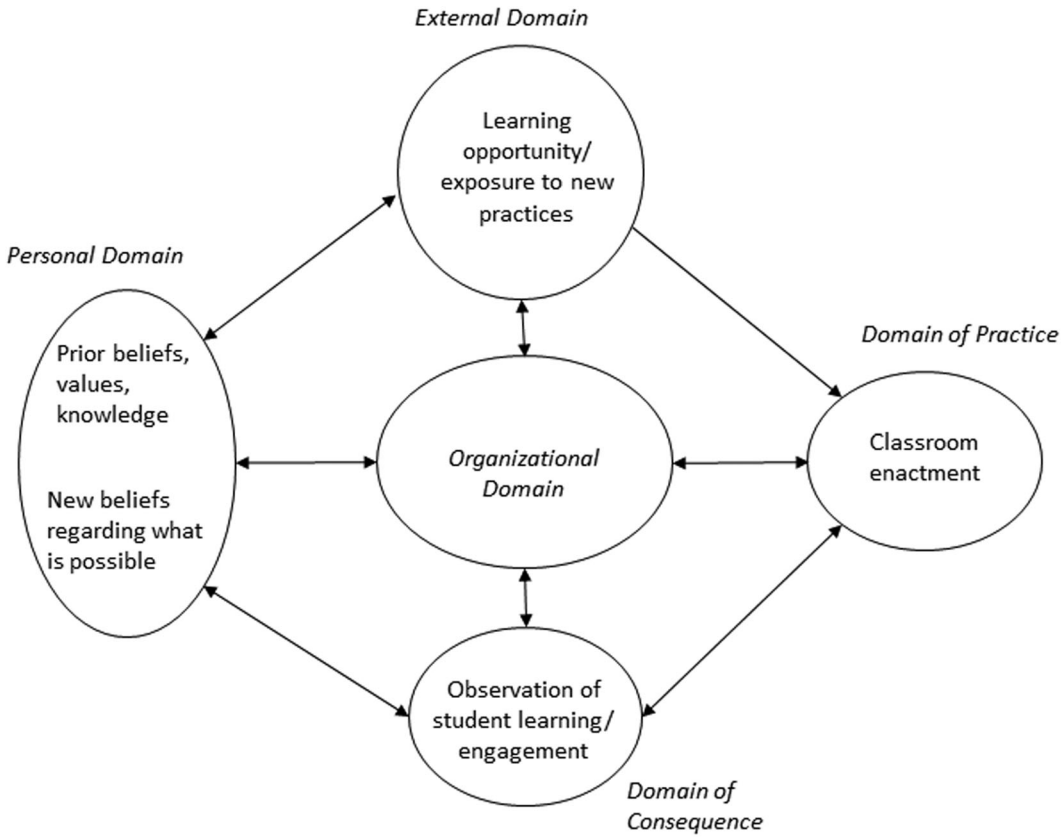

FIGURE 1 The interconnected model of professional growth in an organizational context (PGOC model) (Hayes et al., 2019), based on Clarke and Hollingsworth (2002) framework. Arrows signify sensemaking and reflection

engage in the change process. However, the model provides few details regarding the organizational and social milieus, which have been clearly documented as influencing instructional practice (Gess-Newsome et al., 2003). We, thus, add the organizational domain.

Here, we focus on three specific and pervasive elements within the organizational domain that faculty are likely to draw upon as they consider new instructional practices: Social relationships, institutional norms, and policies (Spillane et al., 2002). The relationships and collegial culture of subgroups of instructors within one organization (e.g., faculty engaged in K12 partnership projects) may play a key role in how instructors take up new practices (Coburn, 2001; Gephart, 1993). If smaller groups of faculty are able to engage in deliberation about instructional reform with other instructors and outside experts, they are likely to engage in more fundamental changes (Spillane & Zeuli, 1999). The ways instructors make sense of new pedagogies are also situated within institutional norms and culture, a system often made up of tacit rules and definitions for valued behaviors (Spillane et al., 2002). In higher education, these norms may include faculties' underlying beliefs about their students' academic preparation and resistance to active learning (Gess-Newsome et al., 2003). Depending on the nature and strength of such norms and the social networks in which they are embedded, faculty may be averse to taking pedagogical risks (Kezar, 2014). In addition, how instructors adapt and implement instructional practices is often influenced by the alignment between new instructional practices and existing institutional structures and policies (Heredia, 2020). For example, in a study of teacher science PD, Allen and Penuel (2015) found teachers had difficulty incorporating the ideas of PD due to conflicting organizational goals regarding curriculum and instruction.

When teachers "made sense of" and constructed strategies that dovetailed instructional innovation with the needs of their organization, they were more likely to incorporate Next Generation Science Standards (NGSS)-based instructional practices.

Adding an organizational domain necessitates bringing in aspects of organizational theory that can explain how instructors make sense of cues in the organizational environment, called organizational sensemaking (Allen & Penuel, 2015; Coburn, 2001). Clarke and Hollingsworth (2002) proposed reflection and enactment as analytical tools for understanding the processes that take place as instructors learn about, reflect on, and incorporate new ideas into their instructional practice. Like Clarke and Hollingsworth's proposals, organizational sensemaking recognizes the recursive relationship between constructing meaning out of environmental cues and taking action. These actions then generate additional opportunities for meaning-making (Coburn, 2001; Maitlis & Christianson, 2014; Weick, 1995; Weick et al., 2005). However, a sensemaking lens extends the interaction between domains (particularly between the organizational domain and other domains) beyond reflection and enactment to account for the role of dissonance or conflicting goals, in the organizational environment (Allen & Penuel, 2015; Weick et al., 2005; Weick, 1995). Research in organizational sensemaking has also called attention to the way emotions and relationships play a role in how people make sense of new information or uncertain situations (Coburn, 2001; Maitlis & Christianson, 2014).

The PGOC model, thus, has five domains: The personal domain, the external domain, the domain of practice, the domain of consequences, and the organizational domain (i.e., social relationships, institutional norms, and policies). As instructors iteratively learn about, enact, and reflect on new instructional practices, they move between the various domains and construct meaning regarding instructional practice. For example, faculty may have existing personal beliefs about K–12 education that lead them to participate in facilitating teacher PD, which then exposes them to new pedagogies. Their perception of the new pedagogy may be negatively influenced by their existing beliefs about college students' need for direct instruction. However, as they try out the active learning pedagogy during teacher PD, their belief about the effectiveness of active learning approaches may change, inspiring them to try it out in their own college classroom. In turn, if their college students' reactions to the new approach are positive, this may further shift their beliefs (Shadle et al., 2017).

Taken together, we use the PGOC model because of its potential explanatory value and because, like teachers, faculty are learning new ideas, reflecting on their instruction, and engaging in the process of change within an organizational context. However, this model has yet to be applied to understand faculty instructional change within school–university partnerships. Thus, in the process of applying this model, we operationalize the general, conceptual PGOC model for this specific context, leveraging the model to understand faculty instructional change. That is, we compare the findings of a particular context against a set of theoretical propositions, with the goal of understanding how each domain influences reported instructional change (Yin, 2009).

4 | METHODS

4.1 | Description of context and PD program

This study took place as part of a larger ongoing study in the western region of the United States focused on a science education PD partnership between a large public university and a county office of education, called the Science Learning Partnership (SLP). The overarching goal of SLP was to build capacity for science teaching amongst elementary and middle school teachers. All of the faculty were employed at the same four-year comprehensive university that also served a diverse student population (approximately 30% Hispanic/Latinx, 10% African American, 20% Asian; 60% first-generation college students).

The PD for teachers consisted of content learning with science faculty coupled with pedagogical learning with science coaches from the county office of education. The faculty taught science content specific to their field of

expertise (earth, life, or physical science broadly) at the weeklong summer institutes and three full-day Saturday workshops per year (6 h/day). Faculty primarily taught content separately from pedagogy sessions, however, the science coaches worked closely with faculty to plan and implement content sessions and integrate pedagogy. In addition, faculty participated in the pedagogy sessions during the PD, helped with teacher lesson study, attended planning meetings, and contributed to the development of the PD vision in project meetings with science directors, coaches, and researchers. At the time of their interview, the number of days each faculty had facilitated teacher professional development for the project ranged from 18 to 40.

During the first 3 years of SLP (2012–2015), pedagogical outcomes for teachers focused on inquiry-based instructional approaches, such as observation of natural phenomena, providing evidence to support a claim, and formative assessment probes. In the latter 4 years of this ongoing partnership (2015–2019), the focus of the PD shifted towards implementing NGSS science and engineering practices, with a focus on supporting students' questioning strategies, development of scientific explanations, and modeling of scientific processes. Over 7 years, approximately 450 third–eighth-grade teachers across 10 urban districts participated in this multicomponent program. Teacher participation ranged from a core cohort who engaged in all components of the PD over several years, including summer institute, Saturday workshops, and year-long lesson study, to those who attended one PD session.

Faculty had both external incentives (e.g., summer salary) and internal motivations (e.g., commitment to supporting K–12 science education) for providing teacher professional development. Yet faculty did not initially engage in SLP work to improve their own teaching, nor was the goal of the project focused on faculty learning. Most of the faculty pedagogical learning took place organically during the planning and facilitating of teacher professional development in partnership with science coaches, as well as through observing the pedagogy sessions. It is the authentic, practice-embedded nature of faculty learning that we find interesting: This was not faculty professional development, yet all the faculty reported learning and enacting new pedagogies as a result of their participation in the school–university partnership.

Because many thousands of science faculty across the nation facilitate teacher PD (Zhang et al., 2011), school–university partnerships like SLP may be a largely unexplored but potentially powerful space of faculty learning, with iterative opportunities for faculty to try out new pedagogies alongside K–12 educators and a community of like-minded colleagues. That said, we are not claiming that SLP was an ideal space of faculty learning; instead, we believe it is a fruitful space for understanding how faculty learn while situated in the practice of educating teachers.

4.2 | Sample

Although this study was part of a larger project in which the researchers were present at all PD and PD planning sessions, the main source of data on which we predicate our claims is an interview with each faculty member ($N = 8$) who participated in SLP as facilitators of PD and content experts. These interviews took place over 7 years; each participant was interviewed after they had participated in the project over a year (Kvale, 1996).

This study applied a purposive sample (Miles et al., 2019) because the faculty sampled in this study represent nontypical cases (i.e., these faculty opted into a time-intensive program that most science faculty typically do not engage in; e.g., Ebert-May et al., 2011). Thus, the participants included in this study were selected because they provide unique, first-hand insights into how science faculty engagement in a professional learning program with K12 educators shape their university instructional practices. Further, the context of the longstanding SLP project and significant involvement of a relatively large number of science faculty from the same university provided a unique opportunity to examine commonalities and differences across faculty.

As shown in Table 1, the faculty represented both males and females, a range of scientific disciplines, various academic ranks, and differing lengths of participation in the SLP (2 to 5 years). Faculty participants taught mostly

TABLE 1 Background information for faculty participants, at time of interview

Name[a]	Gender	Science dept.	Years in SLP	Academic Rank	Prior teaching[b]	Years in current inst.
Daria	Female	Biology	4	Assistant	Limited teaching as postdoc; no teaching in graduate school	4
Jessica	Female	Physics	2	Assistant	No prior teaching	2
Matt	Male	Earth Sciences	2	Assistant	ESL teaching; TA in graduate school	3
Paul	Male	Chemistry	3	Assistant	26 years of teaching; numerous institutions	5
Carrie	Female	Biology	5	Associate	TA in graduate school; postdoc teaching; lecturer	15
Danielle	Female	Chemistry	5	Associate	TA in graduate school; lecturer	9
Jeremy	Male	Physics	3	Full	Limited TA; no teaching during PhD or postdoc	11
Jim	Male	Earth Sciences	5	Full	Limited TA during graduate school	17

Abbreviations: SLP, Science Learning Partnership; TA, teaching assistant.

[a]Pseudonym.

[b]Teaching experience before faculty appointment at current institution.

upper- and lower-division undergraduate major and general education courses with some also teaching at the graduate level. It is also worth noting that three of the faculty worked at the university for over 10 years, whereas the newer (assistant) professors had recently joined the institution. Jim, Danielle, and Carrie had been collaborating with K–12 educators for many years, demonstrating a long-term commitment to supporting school–university partnerships throughout their careers. Because the interviewed faculty varied across these dimensions (e.g., faculty rank, gender, and science discipline), our sample included diverse faculty experiences and recursive change processes related to their experiences in SLP and university teaching practices.

The findings from the analysis of the faculty interview transcripts were corroborated with (1) detailed field notes and videos of faculty engaging in planning and delivering professional development, and (2) interviews with county office science coaches. This information was used to verify faculty's reports about what took place in the PD planning meetings, the pedagogies explored during the teacher PD, and the faculty's interactions with the elementary and middle school science teachers.

4.3 | Interview approach

Though interviews do not provide objective measures to verify the implementation of particular instructional approaches, they are an ideal method of data collection for understanding individuals' internal processes of reflection, sensemaking, and decision-making about a particular topic (Fontana & Frey, 2000). In this study, the interviews served to obtain information about how science faculty conceptualize their experiences, beliefs, and ideas about instructional change in relation to their participation in SLP. In particular, this study focused on the perspectives of faculty in regard to their own change process, providing a basis for applying the PGOC model to understand faculty change.

A semistructured interview protocol included 15 questions generated by members of the research team that were used to elicit a deeper understanding of faculty's common experience participating in SLP while allowing for emergent discussions (Fontana & Frey, 2000; Kvale, 1996) (Appendix A). Faculty were first asked about their background, where they learned how to teach, and about their current teaching approaches in their own college courses. They were then asked about their experiences with SLP, including the relationship between their participation and their current classroom pedagogical practices. Finally, they were asked about any institutional supports or barriers they encountered as they examined and changed their teaching practices. The interviews (averaging 45 min) were conducted in person, individually in a quiet room, audio recorded with permission, and transcribed verbatim. Approval for conducting the study with human subjects was obtained from the university Institutional Review Board before conducting the study.

4.4 | Data analysis

The interview transcripts were coded and analyzed by the research team in multiple steps using the Dedoose qualitative coding software. Like Olitsky (2017), the research and analysis conducted for this project were predicated on an iterative and evolving relationship between data collection, theory, and analysis. The original data collection and analysis were designed to extend the small body of research conducted by Pomeroy and colleagues (2011; 2010) and Zhang and colleagues (2010; 2011) that showed the ways that faculty facilitating teacher PD influenced their own instructional practices. We conducted an initial open coding based on the research questions (Miles et al., 2019). Following this procedure, we engaged in a thematic analysis in which we constructed a preliminary figure to model the processes that led iteratively to the faculty's self-described changes in practice.

To build an explanation, we adopted a theoretical framework (The Interconnected PGOC Model; Clarke & Hollingsworth, 2002; Hayes et al., 2019) that hewed closely to the processes that emerged in the thematic analysis. Our goal was to (a) apply a model that allowed for understanding of the mechanisms and processes that underlie instructional change and (b) operationalize the model within a higher education context. To accomplish these goals, we engaged in the following steps. First, the existing taxonomy of codes was compared with the PGOC model to ascertain its ability to explain processes present in the data (Miles et al., 2019). Once the model was deemed largely coherent with the data, two authors coded several transcripts again, with a priori specification of categories (i.e., personal domain, external domain, domain of practice, domain of consequence, organizational domain) based on elements of the PGOC model. Within those broad deductive categories, we allowed specific aspects of each domain to emerge from the data (Maxwell, 2012), as well as interactions between the domains that were common across faculty. For example, one commonly experienced interaction was "teachers and coaches provide inspiration and modeling." These predominant interactions are highlighted at the beginning of the results section, then elaborated with evidence as part of the results. We also looked specifically for ways in which the faculty experiences diverged from the framework. The authors met after analyzing several transcripts to discuss codes under each domain, relationships between the domains, discrepancies, and operationalization of the framework. Once discrepancies were resolved and a final codebook was established, the rest of the transcripts were coded by one author.

The PGOC model demonstrated high explanatory value for many of the processes present in the data. The operationalization of the model illuminated aspects of each domain that helped us to understand faculty

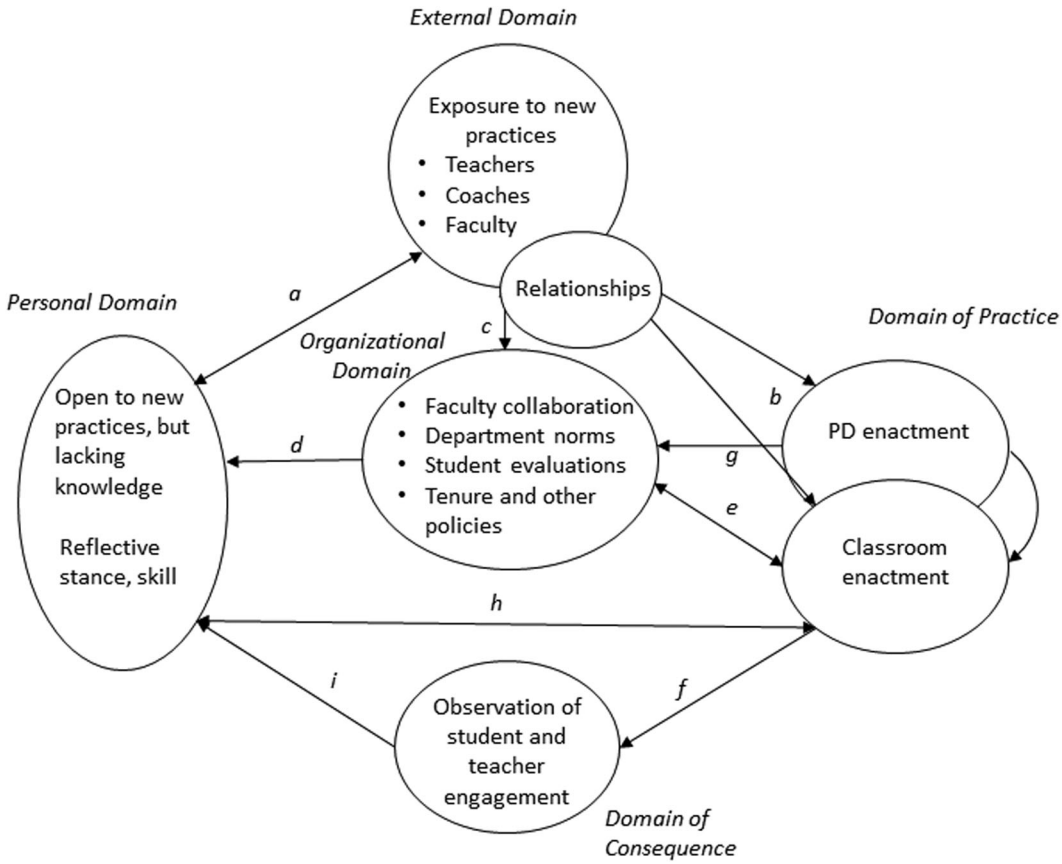

FIGURE 2 Operationalization of the Interconnected Model of Professional Growth in an Organizational Context (Clarke & Hollingsworth, 2002; Hayes et al., 2019) in the context of faculty learning while facilitating teacher PD

learning in this context and provided evidence for how to leverage the model to promote faculty instructional change (Figure 2).

To bolster the trustworthiness of our findings, a draft of the main findings was sent to two of the faculty participants to establish whether our interpretations and summaries aligned with their experiences and perceptions (member-checking; Merriam, 2009). The two faculty were asked to read through the results and provide feedback regarding accuracy in relationship to their experiences. It should also be noted that one of the faculty members is an author on the paper.

5 | RESULTS

In the results, we discuss the faculty's perception of key features of each of the domains and the predominant interactions between domains as represented in the theoretical framework. We first highlight major processes in which faculty engaged as they made sense of the new pedagogical ideas within a social and organizational context. How each of these processes corresponds to the PGOC domains and interactions between domains (Figure 2) is indicated in parentheses. Then each section of the results provides details and evidence regarding the summarized processes.

5.1 | Summary of faculty learning processes

5.1.1 | Faculty wanted to improve their teaching but lacked opportunities to learn pedagogies until SLP

Most of the faculty had a foundational disposition or set of values, that oriented them toward trying new pedagogical approaches (personal domain), yet they had no formal training or mentoring in active learning pedagogies (organizational domain) until SLP (external domain) (arrows a and d).

5.1.2 | Teachers and coaches provide inspiration and modeling

Faculty were exposed to new pedagogies through their work and relationship with teachers and coaches (external domain), shaping both their reflection on teaching (personal domain) and their instructional practices (domain of practice) (arrows a and b).

5.1.3 | Faculty learning community spreads ideas and supports risk-taking

SLP created a learning community (external domain) that shifted local norms (organizational domain), supporting faculty in taking more risks in their instructional practice (domain of practice) (arrows c–e).

5.1.4 | Experimenting with new pedagogies generates feedback in a lower-stakes environment

Experimentation in the context of PD (external domain) allowed faculty to try out new pedagogies (domain of practice) with less institutional pressure (organizational domain) and observe teachers' positive reaction (domain of consequence) (arrows b, f, and g).

5.1.5 | New strategies are taken up in the college classroom

Understandings garnered from reflective practice (personal domain) and PD implementation (external domain) support faculty enactment of active learning strategies in their college classrooms (domain of practice) (arrows b and h).

5.1.6 | Student reactions inform instructional practice

As they enacted the teaching strategies, they learned in SLP (external domain) in their own university courses (domain of practice), faculty felt a sense of goal accomplishment (personal domain) because of the positive reactions of their college students (domain of consequence) (arrows b, f, and i).

5.1.7 | Alignment with organizational norms, structures, and policies shapes instructional change

Faculty sensemaking regarding the alignment between their PD work and the organizational context (organizational domain) influences their participation in the PD (external domain) and enactment of new pedagogies in college classrooms (domain of practice) (arrows c and e).

5.2 | Faculty wanted to improve their teaching but lacked opportunities to learn about pedagogies until SLP

As a foundation, all of the faculty started out with a disposition or set of values that included an openness to new strategies, an internal drive for improvement, a reflective practice, and an interest in science education. As Danielle put it, "I would say that definitely my persona probably contributes to it…I was receptive to the ideas postulated at SLP." Several other faculty members discussed a continuous drive to become a better teacher, based on a commitment to student learning. Jeremy described, "I'm a teacher and this is my chosen profession, and I want to do it well." He talked about how it depressed him when students did not do as well as he had hoped, then added, "Why do I try new things? Because I want to get rid of that feeling… I want to feel at the end of the day like, wow, almost all of them really learned a lot."

Although the faculty may have had dispositions toward trying new pedagogies, access to pedagogical resources, and professional learning opportunities were crucial for the implementation of new instructional practices in their college courses. Like most science faculty, they were not formally "taught how to teach," thus seeing and hearing about K–12 strategies (especially those identified in NGSS) were eye-opening for them (organizational domain). Carrie described, "I've always wanted to try something but then never had the right resources to do it… I think I was born a teacher…it's always been sort of in me." Matt also lamented not having the tools to change his practice before participating in SLP, even as he recognized the challenges of his approach. He reflected, "What we were doing wasn't really working for a lot of people… Just straight sage on the stage, direct instruction all day long." In this comment, Matt was recognizing how his students needed more active learning. He went on to discuss how participation in SLP reinforced that perception and gave him tools to move away from direct instruction. Existing dispositions (personal domain) played a role in how and why faculty participated in SLP and their uptake of the new ideas they encountered, yet they needed access to pedagogical resources and tools to move beyond recognition and toward actually shifting their practices (external domain).

5.3 | Teachers and coaches provide inspiration and modeling

5.3.1 | Teachers

When Jim was asked what most impacted his shifts in instructional practice, he said,

> *I'd say the majority came from my working with teachers…working with teachers who are struggling to… implement NGSS…it's really working with the teachers where the rubber hits the road…I really do want to implement the spirit of NGSS in my classroom, you know?*

Jim learned new pedagogical strategies while helping teachers with content during lesson study and in PD workshops. Jim went on to say, "a lot of the activities that I do in the classroom now, I got from [the teachers in SLP]." As another example, in her biology course for nonscience majors, Carrie implemented a series of lessons on climate change adapted for her college students from an instructional unit written by a team of SLP teachers.

Several faculty participants also mentioned learning from teachers to take a more reflective stance and growth mindset toward their teaching. As Jeremy stated,

> *K–12 teachers definitely think much more critically about their lessons and their curriculum than we do… That wore off on me a little bit just being involved in all those summers of them intensely developing these lessons. That definitely made me think a little more critically about what I'm teaching.*

Jim echoed these sentiments, claiming he learned from the teachers about "being mindful or purposeful about the way you teach. That's something I've really learned from them, especially from lesson study."

Similarly, Matt talked about the ways in which the teachers he worked with inspired him to have a growth mindset about his teaching; that is, that his instructional abilities and skills were malleable and could be improved with reflection.

> *I think the teacher leaders… are incredibly inspiring with the amount of energy that they bring and the constant desire for improvement…They'll look at something and they're always asking, "How can we make this better?"…It helps me keep motivated in my own teaching.*

These faculty sentiments were supported by observation data from PD sessions. Faculty and coaches often asked teachers how they would implement or adapt particular content to their K–12 classrooms. Teachers would bring up ideas and resources they shared with the group. As an example, during one PD, the science teachers discussed the benefits and challenges of having students build a model of the lungs using balloons and soda bottles versus examining prebuilt models to learn the concepts. Teachers reflected on the importance of identifying learning goals to guide the activity and also gauging to what extent actually building the models creates buy-in from students or distracts from the ultimate goal. With this discussion, the teachers demonstrated how they centered student learning outcomes and backward design in lesson planning. As shown in later sections, several faculty identified backward design as a pedagogical strategy they learned in SLP and eventually began implementing in their college courses.

Faculty witnessed many discussions like this as teachers demonstrated their commitment to continuously improve as professionals. Thus, it can be seen that working with teachers served as both a source of new information (external domain), and an avenue for reflection on individual beliefs (personal domain) and classroom instruction (domain of practice). Overall six out of eight faculty talked about learning specific strategies or approaches from the teachers.

For about half of the faculty, this learning was facilitated by a professional relationship with teachers, wherein faculty felt a sense of camaraderie and professional respect. As Danielle said, "I've learned that their [teachers'] struggles are not that much different than my struggles (laughs), which is good, I mean I like the camaraderie. I've enjoyed working closely and deeply with those who I have had the chance to." Carrie echoed this sentiment, stating, "I love working with [teachers]…It's really this two-way learning interaction with the SLP teachers because I've learned so much from them." These faculty did not consider the relationship with teachers to be a one-way imparting of content knowledge; the relationship was characterized by respect. As Jim described, "They are so creative and they have all these different activities…Brilliant!… I'm always learning these great activities from [the teachers]." Together the faculty and teachers explored challenges in students' conceptual understanding, shared teaching and assessment strategies, and reflected on teaching—all of which played a substantial role in shifting faculty teaching practices, and relatedly, their disposition toward teaching.

5.3.2 | Coaches

Nearly all faculty also discussed how science coaches employed by the county office modeled active learning pedagogies during the PD and assisted the science faculty in integrating these approaches into their science content session. By design, each day of PD was supported by 3–5 h of collective planning between faculty and coaches wherein faculty and coaches each brought their area of expertise to the table (content and pedagogy, respectively) and negotiated inquiry activities, pedagogical tools, and teacher learning experiences. This process required faculty and science coaches to work through various points of tension, such as how to balance adult-level science content and elementary or middle school level activities that teachers could use in their classrooms. As one of the coaches commented during an interview, "I've been having individual conversations with different faculty [involved in SLP] and discussing… let's say you want to look at [specific scientific concept], how are you choosing what is it that you want as a learning outcome, what are the standards expecting kids to be able to do, and what's the adult level content teachers need?" This coach was reflecting on the challenges of balancing faculties' desire for teachers to gain deep content knowledge with the support SLP teachers need to design engaging science lessons for their students. Over time faculty learned with and from coaches.

Jeremy found that his interaction with the coaches encouraged him to be more deliberate in using the student assessments to inform his instruction.

> *SLP forced us to interact with people who all they do is think about the process of teaching, so I would say that had a really significant impact on making me a much more reflective practitioner of teaching, so I was really thinking about… "How am I using the results of assessment?" "How am I engaging my students?"*

The interaction between faculty and coaches also paved the way for the uptake and use of specific pedagogical strategies in their courses. For example, Jim noted,

> *in SLP, we've had Sue [coach] talk about the integration of math… So, my knowledge of…how I might integrate math better with my courses [grew]—and I made a very conscious effort of increasing the math content of my courses because of that.*

Other faculty also mentioned learning specific strategies from working with coaches, including whiteboarding (i.e., small group activities using whiteboards to facilitate student learning) and think–pair–share activities (i.e., discussions in which students think about their ideas, share with a neighbor, then share out to the whole class). As Matt said,

> *[Coaches] are pedagogy specialists, really. Which is great for me because I'm not at all in any way a pedagogy specialist…They know all these tactics that are brand new to me…I can just spew out a content idea and they can be like, "Oh, you know what we should do with that is think, pair, share, or…"*

In these examples, the faculty describe a process of being exposed to new ideas (external domain), reflecting on how that might translate into instructional practice (personal domain), then enacting the ideas in their classrooms (domain of practice).

5.4 | Faculty learning community spreads ideas and supports risk-taking

The majority of faculty (five out of eight faculty) mentioned that the opportunity to collaborate with other faculty as they facilitated teacher PD also encouraged idea sharing amongst colleagues and shifted norms regarding instructional innovation. As Jeremy put it,

> *It definitely changed things for me because…you feel a little safer when it's two people, and you can try something crazy because it's not just on me. We're going to do it as a team and I don't feel like I have to have everything under control, and just being able to talk to somebody and bounce ideas back and forth, I think is very useful.*

As this comment indicates, some faculty may have felt they were taking a risk in trying out more interactive teaching practices in their own courses, so collaborating with other faculty to design PD provided an additional layer of support as they experimented. Here Jeremy was making sense of existing organizational norms (organizational domain), resulting in him feeling like it was a risk to try new practices. This risk was mitigated by his ability to try out new practices in the lower-stakes environment of PD (domain of practice), and collaborative relationships with other faculty (external domain).

Other faculty affirmed that the SLP created a learning community (external domain) that shifted local norms (organizational domain) regarding instructional practice (domain of practice) (Green et al., 2013; Shadle et al., 2017). Teaching innovation was encouraged and active learning pedagogies were valued amongst participating science faculty. Matt, a new faculty member, put it succinctly: "The nice thing with SLP… is that I was able to be incorporated into a community of practitioners [faculty] who already had a bunch of experience doing all these things." He went on to talk about the openness of the group: "Generally people are fairly open with sharing their opinion, their skills, their experiences, and their knowledge. That's been a nice benefit of SLP." Jessica also spoke extensively about getting ideas from other SLP faculty about instruction. Both Jessica and Matt were newer faculty members when they began working with SLP, so the connections and open culture afforded by SLP allowed them to learn from other faculty as they tried out new teaching strategies.

5.5 | Experimenting with new pedagogies generates feedback in a lower-stakes environment

In their role as content experts during teacher PD events, the faculty had opportunities to experiment with specific pedagogical practices, such as whiteboarding, small group discussion, and questioning strategies to encourage science discourse in a lower-stakes informal environment. For example, Paul talked about having an opportunity to utilize teaching strategies aligned with NGSS during the PD sessions:

> *Our typical thing is to try and find some sort of an anchoring phenomenon that is going to contain within it physical concepts that hit on several different learning objectives. And then we'll spend a week during the summer institute trying to pull out the individual physical concepts and exploring them in more detail, so that we can go back and try and provide a more complete description of this anchoring phenomenon.*

During the PD, Paul and his colleagues were able to use a phenomenon-based approach to teaching science that they would not typically try in their own college courses. The use of innovative teaching approaches in PD was corroborated in observational data of PD. As an example of this type of anchoring phenomenon, teachers in one session started out by doing an experiment with a candle in a jar and watching the water levels change. This peaked the teachers' interests and over the course of the next several sessions, the PD facilitators scaffolded opportunities for the teachers to better understand the underlying principles and how to introduce these concepts to their students. Over the 7 years of this study, almost every session was planned and carried out by coaches and science faculty together, incorporating both adult-level content and activities and lessons teachers could use in their own classrooms. Although the ratio of direct instruction to engagement in science inquiry varied by the instructor and by year, every content session had opportunities for teachers to engage in scientific discourse, try out inquiry approaches, and use project tools such as claim–evidence–reasoning (McNeill & Krajcik, 2008).

Five of the eight faculty mentioned PD as an important space to practice new pedagogies. As Jeremy said,

> *There's some luxury you have in some of these…workshops to [try out new strategies]. You don't feel the pressure to get through a certain number of content topics. You can say we're going to spend a whole day on this subject…and so I really felt we were able to do a lot of activities. Whiteboarding and things like this that take some time, but I thought they were positive for the teachers.*

This is an example of a faculty member reflecting on how facilitating teacher PD (external domain) supported his enactment of particular pedagogies (domain of practice). He was simultaneously making sense of this opportunity in relation to a particular set of organizational norms and policies regarding topic coverage (organizational domain) and teacher reaction (domain of consequence). Faculty often cite time constraints teaching necessary content as major barriers to incorporating more active learning into college courses (Green et al., 2013; Michael, 2007).

5.6 | New strategies are taken up in the college classroom

In addition to using new teaching approaches during the PD sessions, faculty participants began to incorporate these ideas into their college science courses, including a focus on student learning outcomes in course design and a range of active learning pedagogies. All science faculty in this study reported that after participating in SLP they were more intentional about incorporating clearly articulated student learning outcomes into the design of their college courses. The idea of using a backward design strategy (Wiggins & McTighe, 2005) to plan curriculum and activities based on learning outcomes was an ongoing discussion in the SLP PD sessions. As Jim stated, "When I plan my courses now, I really want to see what is the essential material that I want them to know. I want them to have a greater depth with a little less breadth." Student engagement and content mastery are supported when faculty move away from designing courses based on a set of facts, and toward articulating the knowledge, skills, and competencies they want learners to gain throughout a course (Wiggins & McTighe, 2005).

Collaboration with science coaches and interacting with the teachers also helped faculty design courses that use active learning tasks to engage all students more fully in the learning process. All but one of the faculty members reported using such approaches in their college courses. In response to a question regarding practices that she adopted from SLP, Carrie described her shift away from the transmission of information toward a more

interactive, student-centered learning experience: "[I now use] a variety of think, pair, share strategies that always usually involves writing. They're always doing some kind of quick write in class and then some kind of share out."

As another example, Jessica reported that she had shifted a traditional lecture-based course to include the "5E" model of learning used during SLP, including opportunities for students to engage, explore, explain, elaborate and evaluate course content and ideas. She said,

> *Traditionally [this course] is taught in a lecture format… It has the same structure as you would see 50 years ago. We know that's not really the best way students learn… I'm trying to adopt some of these 5-Es, like how do I engage them…I had [an activity] where we were doing electrostatics. I charged up a piece of plastic and I moved the can across the table. They're like, "Yeah, I can move the can without touching it," and so then we talked about that. That was like, "What do you think is happening? Why do you think it's happening?" That was our engage. Then we discussed. Then we explored.*

In this example, Jessica described a learning sequence that she adapted for her college students (domain of practice) based on what she learned in SLP (external domain), her understanding of the best way students learn, and her reflection on student engagement (personal domain).

Several faculty participants talked about using whiteboards and other formative assessment strategies to support student learning during class. As Danielle commented, "Whiteboards is something I definitely got from SLP…the whole idea of guided inquiry…I had an idea…but through SLP I've been able to see how that could be done in a better way." In addition to engaging students in the learning process, having students work through problems and ideas during class can help inform teaching practice by surfacing student learning for instructors (Inouye et al., 2017). Danielle would pose a question for students to solve in groups and,

> *…if I didn't feel good about how that went, then I had my back up questions…If I put up like a conceptual question everybody just nailed it right away then I would skip some of my explanation and go to the next concept.*

Danielle's quote also demonstrated an iterative process of reflection and enactment among components of the PGOC model. She saw whiteboards in action in SLP (external domain), reflected on how they might be implemented in her instructional practice, tried out the ideas (domain of practice), and then reflected on student reaction to inform her next action (domain of consequence).

Not all faculty were able to apply new pedagogical approaches to their university courses. Paul struggled to incorporate active learning strategies in his large 150+ student lecture courses despite a belief that these approaches supported student learning and engagement, stating, "typically I rely mostly on a traditional lecture methodology." He was experimenting in small ways, such as facilitating student discourse during his test review days but felt constrained by the format and structure of the course. As Paul put it,

> *What I liked to do in the past is to have a review day before an exam that had more active learning type exercises, to turn and work with a partner to work through a problem. And again, a lot of our big lecture halls, it's really challenging to do those sorts of things because it's all fixed seating. You can't move around. But working in pairs is not too terrible under those circumstances. So that's something that I would like to be able to get a little bit more of.*

When asked if he had plans in place to incorporate more active learning in the upcoming semester, he said no, but was reflective in his response, saying, "I think that's got to change." Although most of the participating faculty reported substantive changes to their practice, Paul represents a common alternative—where faculty struggle to implement new ideas because of both habit and structural constraints (Brownell & Tanner, 2012). His sensemaking

regarding whether and how he could incorporate new instructional practices he learned from SLP (external domain) into his college teaching (domain of practice) was heavily influenced by organizational structures—the fixed seating and high numbers of students in lecture halls (organizational domain).

5.7 | Student reactions inform instructional practice

When asked how students reacted to the new pedagogical approaches that they were incorporating into their college courses, all of the faculty felt that students were more engaged. Danielle said she thought "the level of engagement was higher," because her class had excellent attendance, even though "normally people don't have good attendance unless it's mandatory." Jessica spoke about how using the pedagogical approaches she learned through SLP increased student participation. She said, "The way they respond is they're definitely more alert… making it more inquiry-based or project-based learning…They loved it." Similarly, Jeremy said a student had come up to him after class and said,

> *"Wow, this class goes by so quickly. I'm always shocked when I look up and it's the end of class." To me that says, okay the students are really engaged, which is…one of the goals.*

Most faculty also said they thought student learning was enhanced by the new approaches, although they were unsure because most had not directly measured the difference. Jessica noted, "There was learning there, more so than I would have expected if I had just kept it in the lecture format." Paul also noticed the difference in student learning when he engaged them in problem-solving:

> *You know, you can see the effectiveness when, rather than giving them answers… give them a chance to develop their own answers… That has really resonated with me out of the SLP programs.*

One of the faculty worked with education researchers to conduct a quasi-experimental study examining the role of whiteboard use in student learning. The use of whiteboards (vs. traditional approaches) was associated with significantly higher scores on students' exams and end of semester grades (Inouye et al., 2017). Seeing the difference in student learning and engagement motivated faculty to continue to try new pedagogical approaches in their courses. As Danielle described, "for me, it's a simple thing—the whiteboards and the group work. I mean I saw it made a difference and the students told me it made a difference."

In reflecting on their enactment (domain of practice) of the new teaching strategies they learned in SLP (external domain), these faculty felt a sense of goal accomplishment (personal domain) because they perceived the new strategies had increased student attendance, participation, and learning within their courses (domain of consequence).

However, it is worth noting that a few faculty also worried about how some students would take the new approaches when they were used to a lecture format. Jim said,

> *What I am concerned about is that oftentimes that students will come to class expecting a passive experience…when I start using the whiteboards I actually have them turn on their brains and start thinking…I've heard from colleagues…that students don't appreciate the opportunity to think in class.*

Students themselves are part of the context in which faculty are making sense of new instructional practices. Faculty may be more reluctant to try out new pedagogical approaches if they believe students will resist based on prior expectations of learning, especially if student dissatisfaction is reflected in their teaching evaluations

(organizational domain) (e.g., Michael, 2007; Owens et al., 2017). To support successful shifts in university teaching practice, there may also need to be a shift in students' expectations for their science learning.

5.8 | Alignment with organizational norms, structures, and policies shapes instructional change[2]

All participants in this study were faculty members at a public, 4-year comprehensive university serving a very diverse population of students. Although not categorized as a research university, science faculty were still expected to maintain a publication record for retention and promotion. During the span of the SLP, four of the faculty were assistant professors, two were associate professors, and two were full professors, thus facing a varying range of expectations and responsibilities. Their sensemaking regarding department and institutional relationships, norms, structures, and policies all had an influence on the degree to which faculty felt they could make changes, which varied by faculty. A few of the ways in which these areas of the organizational domain influenced faculty perceptions and enactment of new instructional practices are detailed in the sections above. In this section, we lay out additional evidence for faculty sensemaking within the organizational context.

5.8.1 | Departmental norms and relationships

Individual faculty members' approach to instructional innovation was affected by their perception of department norms and professional relationships. The words they used to express this perception had an emotional tone, implying that faculty were deeply affected by the alignment or misalignment between their actions and department norms.

For example, faculty in one department spoke of their colleagues and chair as "welcoming" instructional experimentation. As one faculty member stated, "people are definitely supportive of trying new things in the classroom. That's great in our department. Trying new techniques that will engage the students, help them learn, is definitely welcomed." For other faculty members, there was a tension between their work in K–12 education and their department expectations for publication and graduate mentorship. One participant stated,

> *I think what I do is really frowned upon by many members of my department because in their words, it's not what they hired me to do. I'm basically…betraying the department by not doing my basic research in the field in which I was hired…*

Although this faculty member continued to work with SLP, the feeling of betrayal remained a source of tension. In another department, a longtime SLP faculty member felt misunderstood by the department: "I'm a bit of a handicap in my department [in terms of] servicing our graduate program…I think that my department doesn't understand it and they really aren't that interested." These faculty were experiencing an interaction between their commitment to engage in K–12 education (personal domain) and the norms within the organizational context (organizational domain).

Although an established professor in one department felt unsupported, a new professor in the same department stated, "I definitely get support from my department," then described how the original SLP faculty member functioned as a role model:

> *I feel like [the faculty member] has been really successful with that because [my colleague] has a lot of great activities and…can just reach into a magic bag of activities and say, "Here's one that's appropriate for today." I aspire to have that.*

Likewise, another faculty engaged in the project was "tapped" after a colleague left for an administrative position: "I got involved with this project when [my faculty colleague] had to move on. She thought I would be a good candidate… and here I am." Having more than one faculty member involved in facilitating science PD (external domain) may make a difference in how the work is received at the department level, propagating a shift in the norms regarding instruction (organizational domain).

5.9 | Organizational structures and policies

Many of the concerns the faculty had about their departments and college support were directly tied to the tenure, retention, and promotion process and the requirements for high student evaluation scores and scholarly publication. As an example of the latter, one participant felt that the university leadership placed more value on student evaluation scores than classroom teaching and learning. She felt that the administration was supportive "as long as my numbers are good." Other faculty also expressed concerns about student evaluation scores. Jim was worried about trying out whiteboarding in his courses because he had heard from a colleague that her student evaluation scores decreased when she introduced the strategy.

The culture of prioritizing publications in the faculty's original science field was another element that hampered a focus on improving teaching. As one faculty member stated,

> *I don't feel like there is a lot of institutional support for this kind of work, trying to be an effective instructor and to be innovative in the classroom. They want you to do that, but…not at the expense of getting publications out. It's a big disconnect in what they say their priorities are and what they actually support.*

These sentiments align with research indicating that institutional structures often reward faculty for research output above teaching innovation, through tenure and promotion, campus recognition, and resource allocation (Bouwma-Gearhart, 2012; Brownell & Tanner, 2012).

On the contrary, there were occasional areas of alignment between the strategies that faculty were seeing in SLP and other campus initiatives; these areas of alignment appeared to accelerate faculty absorption of new ideas. For example, several of the faculty had obtained grants from the university to transform particular courses into more active learning experiences. Danielle described, "at a very high level there is a commitment to improving teaching and I think that counts. There's evidence of that from the [instructional improvement grant] for example."

Other programs also resonated with the SLP approach. Paul participated as a faculty liaison to the supplemental instruction program for undergraduate science majors, where he learned techniques to more actively engage students. He described: "Some of those things like turn and talk… I think that bringing those two things [SLP and supplemental instruction program] together has been particularly helpful for me." Additional institutionally supported opportunities for faculty to learn about pedagogical innovations amplified the ability of PD facilitation to support faculty instructional change (Furco & Moely, 2012; Sunal et al., 2001).

Participants mused about what might support a broader cultural shift in the instructional approach. Several of the faculty mentioned the need to reduce teaching load to "hone their craft." However, having additional time may not mean faculty spend it learning to be a better teacher. Without a shift in institutional incentives, particularly regarding tenure and promotion, faculty may spend the extra time on publications and other highly incentivized activities. Representative of many faculty comments, Carrie argued,

> *[There needs to be] more recognition, especially in the [tenure] process, for instructional innovation…We are a teaching institution. That's our primary mission…*

Though they demonstrated a deep commitment to improving their teaching practice (personal domain), all faculty discussed ways in which their sensemaking around instructional practice (domain of practice) was influenced by relationships and norms, as well as dissonance or alignment between what they were learning as they facilitated PD and policies regarding time-use, campus resources and priorities, and their own career advancement (organizational domain).

6 | DISCUSSION

In this study, we present a framework for understanding faculty learning and change as an application of the Interconnected Model of Professional Growth in an Organizational Context (PGOC model) (Hayes et al., 2019; Clarke and Hollingsworth, 2002). This study documents the processes by which involvement in facilitating PD for K–12 teachers supported shifts in faculty science instruction towards more active learning pedagogies, extending and theoretically grounding existing findings from a small group of studies of faculty-led PD (e.g., Pomeroy et al., 2011; Zhang et al., 2011).

The PGOC model provided explanatory value in understanding the process of faculty change. Each element (the personal domain, external domain, domain of practice, domain of consequence, and organizational domain) played a role in shaping faculty change as evidenced in the data. The change process occurred in a way that was iterative and reflexive, as faculty made sense of each domain in relation to others. Below, we discuss both the processes of instructional change (RQ1) and the ways in which individual characteristics, social interactions, and organizational contexts shape instructional change (RQ2).

We found that participating faculty came in with dispositions and values favorable to learning and trying new strategies, but lacked opportunities to learn new pedagogies. These predispositions likely positioned faculty to be open to learning new teaching approaches and shifting their own instructional practices (personal domain). Yet, as noted in the literature, these individual dispositions were also influenced by organizational norms and available resources (Birt et al., 2019) (organizational domain). Although they were open to learning, many of the faculty had only been peripherally introduced to active, student-centered teaching approaches before they began work with SLP. The existing literature supports this finding; limited opportunities for professional development related to teaching is often cited as a barrier to instructional improvement in higher education (Brownell & Tanner, 2012).

Through their participation in SLP, faculty were exposed to other professionals (teachers, coaches, and other faculty) who had skills and knowledge not usually available to them in their department or university. Thus, their external domain was expanded, affording learning opportunities that influenced their instructional practice. For some, their learning was enhanced by long-term relationships with teachers. For example, faculty described their relationship with teachers as "camaraderie" (Danielle) and a "two-way learning interaction" (Carrie). Thus, in this context, professional relationships were an important element that facilitated the uptake of new ideas (external domain), shifts in pedagogical beliefs (personal domain), and enactment in practice (domain of practice). Previous research documents the importance of relationships where faculty and teachers collaboratively design instructional materials or conduct experiments, in which both groups feel valued and supported throughout the process (e.g., Brown et al., 2014; Knowlton et al., 2015). At the same time, competing priorities of K12 versus higher education teaching contexts and differing communication styles can make it difficult to foster these types of relationships in faculty-led PD (Tanner et al., 2003; Zhang et al., 2011).

SLP also served as a community of practice among faculty, characterized by curriculum planning and teaching together. In describing their collaboration with other faculty, interviewees mentioned how doing the PD "as a team" made them feel safe (Jeremy) and how other faculty being "fairly open" with sharing expertise felt supportive (Matt). For many of the faculty, facilitating the PD provided a low-risk context to try new pedagogical approaches, shifting local norms among small groups of faculty as they de-privatized their teaching, and allowing them to receive feedback and ideas (organizational domain; domain of practice). For these faculty emotions and

relationships, both tenets of sensemaking played a role in how they made sense of risk and instructional innovation in their pedagogical environments (Coburn, 2001; Maitlis & Christianson, 2014). This type of support is quite atypical for science faculty who often operate in an institutional environment where faculty have little time and incentive to discuss teaching practices with their colleagues, limited pedagogical support, and institutional norms that can serve as barriers to pedagogical innovation (e.g., Birt et al., 2019).

At the same time, faculty also began transferring these new teaching approaches used in PD into their own college classrooms (domain of practice). Their pedagogical innovations were aligned with active learning practices outlined in the literature, including opportunities for student problem-solving such as whiteboarding (Inouye et al., 2017), greater use of formative assessment (e.g., Pedrosa de Jesus & Moreira, 2009), and a more concerted backward-planning approach (e.g., Carlson & Marshall, 2009). Just as K–12 students benefit from active learning experiences, these pedagogical approaches have been shown to encourage higher levels of engagement and content mastery among college students (Freeman et al., 2014). Faculty observed such engagement among their students, providing further encouragement for their instructional change (domain of consequence). However, they also worried about resistance from their students at having to participate in active learning during classes and the potential repercussions on their student evaluations (organizational domain). That said, because SLP was not specifically dedicated to faculty learning, faculty had little opportunity to focus explicitly on how active learning pedagogies affected their college student learning. Thus, although faculty spoke of incorporating numerous active learning strategies, SLP did not necessarily foster in faculty an inquiry-based approach to continuous instructional change.

Additional aspects of the organizational domain were central to the process by which faculty considered and implemented instructional changes. As they did when they discussed collaboration, faculty also used emotional terms to describe how norms and relationships within their department influenced their thinking about participation in SLP and instructional innovation (Maitlis & Christianson, 2014). For example, some faculty felt their department "welcomed" instructional innovation, whereas others felt like they were "betraying" or "a handicap" for their department. Negative feelings were mitigated to some extent in departments with more than one SLP participant, again indicating the importance of communities of practice.

In addition, the dissonance between their desire to focus on instructional innovation and the tenure and promotion process weighed on faculty minds. These barriers to change are well-documented in the literature (e.g., Anderson et al., 2011; Birt et al., 2019) and can influence the way faculty make decisions about how they prioritize their time and advance their careers. Yet when faculty perceived some alignment between institutional policies, resources, and instructional change, such as an instructional improvement grant, they felt the resonance of institutional support and SLP participation bolstered their learning. A sensemaking lens allows for moving beyond a conceptualization of the tenure and promotion process as simply a barrier, and towards a more nuanced understanding of the ways dissonance and alignment stymie or support instructional innovation (Allen & Penuel, 2015; Heredia, 2020). Our findings indicate that incentives embedded in university structures (e.g., instructional innovation support grants) may create pivotal opportunities for alignment between faculties' personal quest for instructional change, external opportunities for pedagogical learning, and institutional policies.

The purpose of this study was to understand the process of faculty change. This study describes the nature and function of the five domains, and allows for an examination of the interactions between domains, surfacing a process of reflection, enactment, and sensemaking. Examining the iterative microprocesses holistically gave rise to the operationalization of macroprocesses documented in Figure 2. It became clear that faculty began with dispositions oriented towards teaching (personal domain). Faculty's participation in SLP exposed them to new instructional practices that were largely unavailable in their organizational domain (external domain). Adoption of these new practices was facilitated by the professional relationships that emerged as faculty worked with coaches and got to know teachers, and by learning a more reflective stance towards teaching from teachers (personal domain). They also benefited from trying out new practices in the low-risk environment of PD (domain of practice). As they transitioned to trying active learning approaches in their college classrooms (domain of practice), they were encouraged by student engagement (domain of

consequence), which resonated with their instructional goals (personal domain). Simultaneously, adoption of the new practices in college classrooms was hampered for some faculty by their existing beliefs about students (personal domain) and their perceptions of organizational norms, policies, and department relationships, which made instructional innovation a riskier proposition (organizational domain).

6.1 | Limitations

Some limitations of this study are worth noting. First, this study was exploratory in nature due to the novel approach of examining faculty learning and change within a school–university partnership context. Although we interviewed all faculty involved in the project over several years, our sample size remains small and pertains to the experiences of faculty at only one university. There was variation in the characteristics of faculty represented in this study (e.g., rank, science discipline, gender, and length of participation in the partnership), yet they shared common values and interest in supporting K–12 science education and improving their college teaching practice. The faculty were also primarily White. Thus, findings from this study may not generalize to faculty of color or science faculty who do not hold such dispositions.

Another limitation of this study is the cross-sectional and retrospective nature of the interview data. It is possible that the faculty's process of learning and interaction varied at the beginning compared to the end of their participation in SLP. Future research is needed to longitudinally examine faculty change in school–university partnerships over multiple time points. Pursuing these lines of inquiry will also contribute to further testing the PGOC model and examining how individual characteristics, social interactions, and organizational contexts shape faculty learning. Finally, to bolster our findings from faculty interviews, examining more direct evidence of faculty change in instructional practice (e.g., videos of college teaching) should be used in future work.

Finally, the nature of the research team is both a strength and limitation of this study. At the time of data collection, three of the authors were researchers on the project, two in the role of postdoctoral scholar. Another author was herself a faculty member who was facilitating professional development. No authors were in a supervisory role for faculty, which may have facilitated an honest dialog, particularly when the faculty member conducted the interviews. However, there may also have been hesitancy to share struggles and challenges with researchers positioned as pedagogical experts.

6.2 | Implications

Educating the next generation of scientists and scholars is central to the mission of higher education. Yet, despite growing evidence that active learning strategies significantly improve student learning and engagement, the majority of college-level science courses continue to follow the traditional, lecture-based format (Freeman et al., 2014). Traditional faculty professional development often consists of short-term and disconnected approaches designed to serve faculty across disciplines without regard to their underlying beliefs and goals for instruction (Henderson et al., 2011). This study presents research on another avenue by which faculty can learn about new instructional practices, try them in their own classrooms, and engage in an ongoing and reflective process of instructional change. Moreover, we operationalize a model that affords an understanding of the processes by which faculty change their practice and the conditions that shape these changes.

These results have four key implications. First, they contribute to literature that builds a case for acknowledging the powerful effects of faculty participation in teaching K–12 science PD on science *faculties*' teaching practice. Shifting faculty instructional practice has been an elusive goal (Henderson et al., 2011; Stains et al., 2018). Facilitating science-focused teacher PD may provide an important tool in this effort by providing both exposure to new strategies and grounds for practicing them. Second, the study provides a theoretical model and empirical

evidence for the processes by which participation shapes faculty shifts in practice, which in this study were iterative and dependent on opportunities to try new ideas in a low-risk environment, collaborate with others, and observe student reaction. Third, the results resonate with a large body of research that demonstrates the role played by collaboration and professional relationships in supporting learning and change (e.g., Birt et al., 2019; Gehrke & Kezar, 2019), demonstrating their salience in a faculty learning environment and extending the literature by documenting the importance of relationships across institutions, such as those between K–12 teachers and faculty. Finally, areas of dissonance or alignment within faculties' organizational environment played a major role in how they made sense of instructional innovation. Areas of dissonance ranged from worry about student evaluations to feeling like their focus on teaching was betraying their department. Areas of alignment included structural supports such as a faculty instructional improvement grant. These findings speak to the importance of university leadership disseminating a coherent message regarding instructional innovation, risk-taking in the classroom, and time allocation. Such findings, if replicated in other contexts, will help guide grant-making and PD planning efforts to attend to opportunities for relationship building and reciprocal learning.

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ENDNOTES

[1]For the purpose of this paper, the term "faculty" is used to refer to instructors at institutions of higher education, including tenure-track faculty, non-tenure-track faculty, lecturer, and so forth. Additionally, the term science faculty is used to refer to instructors teaching in any science discipline.

[2]Due to the sensitive nature of the discussion outlined in this section we chose not to use faculty pseudonyms for certain comments to further protect the identity of faculty participants.

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APPENDIX A: FACULTY INTERVIEW PROTOCOL

I. **Faculty background**
   1. Tell me about your background as a science educator before coming to your current institution.
   2. How many years in your current position?

II. **Current teaching & learning practices in own classroom**
   3. Which courses/types do you teach?
   4. Please share what you consider when you're planning your course.
   5. Focusing on one of your regularly taught courses, tell me about a typical class session.
   6. How did you come to integrate specific teaching practices?
   7. Which practices have you adopted/adapted from SLP and how?
   8. How do students respond to/interact with these practices you mentioned. What have been the impacts on student learning?

III. **Tell me about your experiences in SLP**
   9. Can you tell me about what a typical content session looks and sounds like?
   10. What have been your experiences working with coaches? (What have you learned from your interactions with them?)
   11. What have been your experiences working with the teacher leaders? (What have you learned from your interactions with them?)
   12. Let's talk more about the relationship you see between what you're doing in the classroom now and your experiences in SLP.
   13. What factors do you think motivated you to try SLP-derived practices in your courses? (How do you think this happened?)

IV. **Administrative support**
   14. What impact do you think your practices have made in your department/colleagues?
   15. What support do you get from your department, college, and university to do what you do in the classroom?
   16. What would you like to see happen in this respect?
   17. Anything else you want to tell me that I haven't asked?