Received: 3 February 2023 | Revised: 23 August 2023 | Accepted: 27 August 2023

DOI: 10.1002/sce.21835

RESEARCH ARTICLE

Science Education WILEY

The Classroom-Research-Mentoring Framework: A lens for understanding science practice-based instruction

Alexandra C. Cooper[1] | Molly S. Bolger[2]

[1]Department of Molecular and Cellular Biology, University of Arizona, Tucson, Arizona, USA

[2]Department of Cellular Biology, University of Georgia, Athens, Georgia, USA

Correspondence
Molly S. Bolger, Department of Cellular Biology, University of Georgia, 724 Biological Sciences Bldg, Athens, GA 30602, USA.
Email: molly.bolger@uga.edu

Funding information
National Science Foundation – Improving Undergraduate Science Education, Grant/Award Number: DUE-2020788

Abstract

Reformed science curricula provide opportunities for students to engage with authentic science practices. However, teacher implementation of such curricula requires teachers to consider their role in the classroom, including realigning instructional decisions with the epistemic aims of science. Guiding newcomers in science can take place in settings ranging from the classroom to the undergraduate research laboratory. We suggest thinking about the potential intersections of guiding students across these contexts is important. We describe the Classroom-Research-Mentoring (CRM) Framework as a novel lens for examining science practice-based instruction. We present a comparative case study of two teachers as they instruct undergraduate students in a model-based inquiry laboratory. We analyzed stimulated-recall episodes uncovering how these teachers interacted with their students and the rationale behind their instructional choices. Through the application of the CRM Framework, we revealed ways teachers can have instructional goals that align with those of a research mentor. For example, our teachers had the goals of "creating an inclusive environment open to student ideas," "acknowledging students as scientists," and "focusing students on skills and ideas needed to solve biological problems." We suggest three functions of research mentoring that translate across the classroom and research laboratory settings: (1) build a shared understanding of epistemic aims, (2) support learners in the productive use of science practices, and (3) motivate learner engagement in science practices.

KEYWORDS

instructor discourse, model-based inquiry, research mentoring, science practices, teacher reasoning

1 | INTRODUCTION

Science practice-based instruction envisions students as participants within a community focused on developing knowledge of the natural world. Learners are situated in a context that moves away from direct teaching of content and instead focuses on teaching ways of knowing (Ford, 2008; Manz et al., 2020; Schwarz et al., 2017; Windschitl et al., 2008). The movement to bring authentic science practices into the classroom has pushed for a transformation of classroom teaching (Guy-Gaytán et al., 2019; Schwarz et al., 2022). Yet, determining how to guide students in conducting their own inquiries using science practices has created tensions in teacher implementation (Crawford, 2007; Manz & Suárez, 2018; Varelas et al., 2005; Watkins & Manz, 2022). In this study, we developed a novel framework for thinking about science practice-based instruction. Through our previous work investigating teacher reasoning in the context of a model-based inquiry classroom (Cooper et al., 2022), we hypothesized that teachers may approach science-practice-based instruction in ways that are analogous to research mentoring. Thus, we turned to the literature on research mentoring to identify salient aspects of supporting students both cognitively and socially, while engaged in the practices of science. We suggest that there are some similar features for guiding a science newcomer in science practices across research and classroom contexts.

The decision to promote practice-based instruction is grounded in the idea that students' science learning activities should mirror those of scientists conducting inquiries in a research setting (Ford, 2008; Lehrer & Schauble, 2006a; NGSS Lead States, 2013; Wong & Hodson, 2009). Studies of scientists provide a deep background for understanding the ways of knowing, interacting, and experimenting that are common in research contexts (Ford, 2008; Klahr et al., 1993; Wong & Hodson, 2009). This literature has proven to be a productive resource for conceptualizing practice-based curricula (Berland et al., 2016; Ford, 2008; Justi & Van Driel, 2005; Lehrer & Schauble, 2013; Passmore & Svoboda, 2012). However, understanding the practices of science does not directly translate to how students may learn to participate in these practices (Ford, 2005). In addition, the implementation of practice-based curricula has presented significant challenges, especially with regard to how a teacher may provide instruction in these contexts (Crawford, 2007; Guy-Gaytán et al., 2019; Varelas et al., 2005).

A "science-as-practice" focus in a classroom setting requires rethinking assumptions about the learning process and how it may be situated in a community of legitimate participation (Lave & Wenger, 1991; Lehrer & Schauble, 2006a). The inherent social changes required to foster participation in science practices introduce questions about the role of the teacher in the classroom that are not easily resolved. While there is significant literature on how scientists guide learners in authentic research settings (i.e., research mentoring), this literature has not been widely used to consider the teacher's role in science practice-based instruction.

Through a comparison of research mentoring and teaching in a practice-based classroom, we hope to inspire new ideas about the possibilities for engaging students in scientific inquiries. We begin by identifying three functions of mentoring that we suggest are applicable in both the classroom and laboratory setting:

(1) Building shared understanding of epistemic aims (i.e., framing and goal-setting of the shared purpose to build evidenced-based explanations), (2) Supporting learners in the productive use of science practices (i.e., guidance that supports carrying out the shared purpose), and (3) Motivating learner engagement in science practices (e.g., create a learner setting that invites and supports students' participation in science).

While we do not suggest that these are the only three functions of a research mentor, we do propose these as salient functions for understanding elements of research mentoring that may emerge in a science practice-focused classroom. This assumption is based on our reflections about our own experiences as research mentors and science practice-based teachers. These reflections took place in the context of our previous research on teacher reasoning in science practice-based classrooms (Cooper et al., 2022). Our reflections were enhanced by our review of the literature on research mentoring.

In what follows, we first unpack each of our proposed functions of mentoring as they relate to science as a practice. Second, we review the literature on teaching in science practice-based classrooms. Third, we describe the Classroom-Research-Mentoring (CRM) Framework, which we derive from the literature on research mentoring. Finally, we present two case studies of teachers in a model-based inquiry classroom, examining their teaching using our framework.

1.1 | Supporting science practices

1.1.1 | A mentor builds a shared understanding of epistemic aims

A defining feature of practice is that it is carried out in service of an agreed-upon purpose (Ford, 2015; Gouvea & Passmore, 2017; Stroupe, 2014). Often that purpose, or "shared enterprise," is negotiated within a community that sets out to accomplish a particular goal (Lave & Wenger, 1991; Wenger, 1998). In the case of science, the agreed-upon purpose is to explain some aspect of nature (Ford, 2015). While the purpose of "explaining nature" sounds self-evident as a description of the scientific endeavor, the nuance of what that means and the ways in which this purpose frames actual activity are less obvious. The complexity of the overarching aim of science, as it relates to science practices, is underscored by the amount that has been written about how scientists gain knowledge, that is, the epistemology of science (Ford, 2008; Nersessian, 2010; Wong & Hodson, 2009). Thus, a necessary role of a mentor is to bring a newcomer into the scientific community by building an understanding of the purpose of their shared work. This mentoring function is particularly essential in a science practice-based classroom setting where framing the purpose of the activity is often in conflict with traditional classroom norms and expectations (Crawford, 2007; Ford & Wargo, 2007; Rudolph, 2008; Windschitl & Thompson, 2006; Windschitl et al., 2008; Wong & Hodson, 2009). Because classrooms traditionally provide few opportunities for epistemic agency, students often approach new research experiences without sufficient understanding of their own role in generating scientific explanations. Thus, mentors and teachers have a responsibility to not only provide opportunities for student epistemic agency but also to help them frame their activities as connected to scientific purposes (Miller et al., 2018; Stroupe et al., 2018). We expand upon this challenge in the next section.

1.1.2 | A mentor supports learners in the productive use of science practices

Another defining feature of science practice is that it is composed of a set of interacting activities (Ford, 2015). Practices are defined by the ways that these activities interact, rather than by specific rules or patterns. This can make science practices difficult to learn through didactic teaching because it cannot be reduced to a specific, tangible skill (Ford, 2015). Furthermore, introducing a learner to science by teaching isolated skills that are not situated in an authentic context may contribute to an inaccurate view of the nature of science (NOS; Wong & Hodson, 2009). In theory, science practice-based instruction avoids this problem. However, supporting a learner in the complex cognitive and social work of science practice is not trivial. Each of the interacting activities that compose a practice may be performed with greater or lesser levels of expertise (Berland et al., 2016; Ford, 2008). The success of the science enterprise depends upon how well these activities are executed. Success and failure through participation in practices are central to the learning process of science as a practice, a process in which the mentor plays a key guiding role. In addition, participation in science practice entails taking on the dual roles of an idea generator and one who critiques ideas (Ford, 2008; Henderson et al., 2015). The nature of a newcomer's science learning experiences can determine the extent to which they generate productive experimental ideas (Ford, 2005). A mentor plays a role in judging when a newcomer's ideas and forms of engagement are productive (Engle & Conant, 2002). In general, this productivity is marked by an individual's intellectual progress, but the specifics of productivity are often determined by the discipline (Engle & Conant, 2002; Ford, 2005). Thus, a mentor or teacher needs to provide significant encouragement and feedback as a learner moves from an observation of science to participation in science practices.

1.1.3 | A mentor motivates the engagement of a learner

The participation of a learner in the process of science depends upon their sustained engagement and interest, that is, their motivation (Linnenbrink-Garcia et al., 2016). A mentor plays a key role in facilitating a science newcomer's motivation by promoting intellectual interest, providing intellectual autonomy and authority to address problems, building self-efficacy, and normalizing the process of science to minimize potential performance anxiety (Burden, 2000; Engle & Conant, 2002; Linnenbrink-Garcia et al., 2016; Pfund et al., 2016). Part of motivating newcomers in a research setting includes positioning them as epistemic agents, which provides them with opportunities for productive disciplinary engagement (Engle & Conant, 2002; Miller et al., 2018).

Additionally, a mentor is tasked with inviting the newcomer into the scientific community and facilitating their legitimate engagement with the activities of that community, ideally in ways that promote their sense of belonging. Research on why newcomers choose to persist in a science field underscores the connection between science motivation and one's relationships within a science community (Estrada et al., 2011; Graham et al., 2013). Recognition from others and a sense of belonging within a scientific community are crucial aspects of how one develops a scientific identity (Carlone & Johnson, 2007; Starr et al., 2020; Wenger, 1998). While the literature on science practices does not emphasize these aspects, there are key intersections with what is known about communities of practice in general. More experienced members of a community of practice play a role in providing legitimate ways for newcomers to participate. These forms of engagement are essential for the situated learning of the newcomer (Lave & Wenger, 1991). Over time, the social interactions that take place within a community of practice can have a strong influence on how newcomers see themselves and the development of aspects of their identity (Lave & Wenger, 1991).

Also, relevant to promoting newcomer engagement is coping with the experiences of failure and frustration that are inherent to authentic inquiry (Corwin et al., 2022; Goodwin et al., 2021). The way a mentor supports a learner through the emotional aspects of scientific inquiry may influence a learner's motivation to persist through these challenges (Pfund et al., 2016). Related work on students' feelings and emotions in a classroom setting brings attention to the role of the teacher in supporting students' epistemic affect during practice-based instruction (Gellert, 2000; Jaber & Hammer, 2016; Jaber et al., 2022).

1.2 | Documented challenges of teaching science practices

In K-12 education there is a move to take a "practice turn" to address the disconnect between school science and authentic science practices (Forman, 2018; National Research Council, 2012). Specifically, this reform seeks to engage students in science practices, such as modeling, carrying out empirical investigations, using evidence-based arguments, and drawing conclusions from evidence (Ford & Forman, 2006; Forman, 2018; National Research Council, 2012; Passmore et al., 2014). Educators at the undergraduate level are also considering how to incorporate core competencies of science in the classroom, including the ability to apply the processes of science (American Association for the Advancement of Science, 2011). While these types of activities are not commonly referred to as "science practices" within undergraduate education, the reform documents describe engaging students in "skills" like designing experiments and interpreting and evaluating data (American Association for the Advancement of Science, 2011). Course-based undergraduate research experiences (CUREs) are one mechanism that the undergraduate community has used to bring the process of science into the classroom (Auchincloss et al., 2014; Buchanan & Fisher, 2022). Additionally, science practice-based curricula have begun to emerge in undergraduate chemistry, physics, and biology (Brewe, 2008; Gouvea et al., 2022; Hester et al., 2018; Tien et al., 2007; Walker et al., 2016; Zagallo et al., 2016). We will next review implementation challenges in both K-12 and undergraduate settings, with an emphasis on K-12 education, where more is known about how teachers navigate science practice-based instruction.

Engaging students in the practices of science requires them to, in part, take up the epistemic aims and values of science (Chinn et al., 2011; Ford, 2015; Gouvea & Passmore, 2017; Jaber & Hammer, 2016; Miller et al., 2018). The success of teaching science practices relies upon the creation of instruction that makes these epistemological aspects of science apparent and positions students as epistemic agents (Radoff et al., 2019; Stroupe et al., 2018). A teacher's own lack of experience with authentic inquiries may interfere with this goal (Bismack et al., 2022; Crawford, 2007). To address this challenge, there have been significant efforts to develop K-12 teachers' understanding of the NOS through professional development (PD) opportunities, including participation in short-term research experiences. Outcomes include varied levels of NOS learning among teachers (Davidson & Hughes, 2018; Schwartz et al., 2004; Varelas et al., 2005). Interestingly, even when preservice teachers can provide relatively sophisticated descriptions of the NOS, their level of understanding does not necessarily translate into pedagogical performance (Bismack et al., 2022; Varelas et al., 2005). There is often a disconnect between a teacher's views about science as a practice and teaching science practices (Varelas et al., 2005). This disconnection is not limited to K-12 teachers. Practicing scientists may also experience tension between their ways of thinking within their research communities and their thoughts about teaching in an undergraduate science classroom (Brew, 2010; Malachowski et al., 2020). This type of disconnection can be a barrier to the implementation of science practice-based instruction at all levels of education.

The norms of traditional teaching conflict with setting up a science practice-based community. Creating opportunities for student uncertainty and sense-making requires teachers to be comfortable with being uncomfortable. It is necessary for teachers to be able to navigate their own uncertainty by releasing some of their control over the direction of conversations and trusting students' ability to learn content goals through their participation in practices (Manz & Suárez, 2018). Evidence reveals that beginning K-12 teachers draw on their experience as students to negotiate the routines, roles, and responsibilities of their classroom. However, this leads teachers to use practices that are common in traditional classrooms, which do not align with the routines, roles, and responsibilities of authentic science (Crawford, 2007; Ford & Wargo, 2007; Ko & Krist, 2019; Rudolph, 2008; Windschitl & Thompson, 2006; Windschitl et al., 2008). For example, when helping students navigate modeling as a scientific practice, K-12 teachers may find it challenging to elicit and value different student ideas because they want students to reach a consensus on specific content knowledge objectives (Guy-Gaytán et al., 2019; Ko & Krist, 2019). In many cases, teachers may revert to implementing more teacher-centered strategies without realizing that these traditional supports conflict with the goals of science practice-based instruction (Biggers & Forbes, 2012). Ultimately, the teacher's role must be renegotiated, as retrofitting the goals and supports from a traditional classroom are often ineffective in supporting students in science practices.

Undergraduate science education is encountering many of the same challenges seen with K-12 teachers. Laboratory courses are a key place where science practices are being introduced through curricular reform. These courses are ones in which student instructors (teaching assistants [TAs]) often serve as the primary teachers. This teacher population shares many similarities with K-12 teachers. First, they are still learning about science and developing their own understanding of the epistemic aims of science (Goertzen et al., 2010; Sandi-Urena et al., 2011). Second, they are also found to rely on their own experiences as a student or teacher in traditional laboratory courses, which conflict with the goals of practice-based instruction (Ginath & Southerland, 2019; Sandi-Urena et al., 2011; Wheeler et al., 2017). Uniquely, TAs are frequently learning to be teachers with limited or no pedagogical training, creating additional challenges that K-12 teachers may not experience (Mutambuki & Schwartz, 2018; Schussler et al., 2015). With the known challenging nature of this type of instruction in both K-12 and undergraduate settings, more work is needed for our fields to think about science practice-based instruction.

1.3 | Conceptual framework: Classroom Research Mentoring

We sought to develop a conceptual framework to explain the key factors and concepts (Miles & Huberman, 1994) of research mentoring in the classroom. To develop this framework, we used available research about undergraduate and graduate research mentoring in laboratory settings. In addition, work describing mentoring in an inquiry classroom setting was included when applicable. Our goal in building this framework was to describe the strategies and approaches used by research mentors to teach their students how to approach scientific work. With our narrow focus in mind, we chose to only include studies that describe what a research mentor does to guide their students when they are doing things like learning technical skills, designing experiments, building scientific ideas, and so forth. This caused us to exclude several articles that focus on mentors' and students' perceptions of the importance of mentoring (Aikens et al., 2016; Dolan & Johnson, 2010; Limeri et al., 2019b), as well as studies about "negative mentoring" (Limeri et al., 2019a; Tuma et al., 2021). We also chose to only include the research mentoring aspects that would likely be transferrable to an inquiry classroom, using our experiences in curriculum design and teaching in this context as a guide for these choices. Therefore, we did not include research on how a mentor may provide certain aspects of psychosocial and career support as these seemed more relevant to one-on-one mentoring of students in long-term research experiences (e.g., Brown et al., 2009; Lunsford et al., 2017; Pfund et al., 2016; Thiry et al., 2011). The resulting CRM Framework characterizes goals and tools used by research mentors with their mentees that could theoretically transfer into a classroom setting (Tables 1 and 2). We have chosen to include the goals of the mentors along with their tools of implementation due to evidence for both in the literature.

TABLE 1 Classroom research mentoring goals for students.

Goals	
Focus students on skills and ideas needed to solve a problem	Gafney (2005); Feldman et al. (2008); Kapon (2016); Pfund et al. (2016); Shanahan et al. (2015); Shore (2005)
Engage collaboratively in a joint inquiry with students	Brondyk and Searby (2013); Kapon (2016); Pfund et al. (2016); Shore (2005); Varelas et al. (2008)
Acknowledge students as scientists	Pfund et al. (2016); Shore (2005)
Celebrate students' research milestones	Pfund et al. (2016)
Foster collaboration between student researchers	Ayar and Yalvac (2016); Feldman et al. (2008)
Create an inclusive environment open to student ideas	Pfund et al. (2016)

TABLE 2 Tools used in the implementation of classroom research mentoring goals.

Tools	
Modeling: Mentor carries out a task so that the student can observe it and build a conceptual model of the processes needed to accomplish the task.	Collins (2005); Feldman et al. (2008, 2013); Kapon (2016)
Scaffolding: Mentor supports the student as they carry out a task. This may include actions like directing student to accessible subtasks or giving assistance needed in the moment to complete the task.	Collins (2005); Feldman et al. (2008, 2013); Kapon (2016)
Articulation: Mentor asks students to state their knowledge, reasoning, or problem-solving procedures coherently to refine understanding.	Collins (2005)
Reflecting: Mentor encourages the student to compare knowledge, reasoning, and problem-solving procedures with those of an expert, research literature, or an internal cognitive model of expertise.	Collins (2005); Pfund et al. (2016)
Exploration: Mentor supports student curiosity by encouraging them to engage in problem solving, often through independent projects.	Collins (2005); Kapon (2016)
Invisible Guidance: Mentor supports a student to succeed in a task with the intention not to be overly directive or obvious to the student.	Feldman et al. (2013)
Recognition: Mentor emphasizes, articulates, or values a student's idea.	Pfund et al. (2016); Shore (2005)

The CRM Framework goals, in Table 1, characterize the overall classroom research mentoring aims and directions for supporting students in science practices in the classroom. These goals are overarching mentoring intentions that may influence decisions teachers make when interacting with students in a science practice-based classroom. The CRM Framework tools describe the specific classroom research mentoring approaches a teacher might use to support students in carrying out science practices in the moment. Importantly, CRM tools are the ways a teacher could carry out CRM goals. Of the seven tools included in Table 2, five of the tools have been previously described in detail in Collin's work on cognitive apprenticeship (2005). These five supports have additionally been used as an analytical lens to describe undergraduate research mentoring (Feldman et al., 2013). We chose to not include the tool "coaching" from this work, as its definition overlaps with other tools (e.g., modeling and scaffolding) causing potential challenges in the application of our framework. In addition to the tools from the work on cognitive apprenticeship, we added the tools of invisible guidance and recognition, based on other work in the field. Invisible guidance describes how a mentor may seek to provide guidance in ways that are "invisible" to the mentee. This tool relies on the teacher's support going unnoticed by the students, allowing the students to feel they have accomplished things by themselves (Feldman et al., 2013). When supporting the process of inquiry for a newcomer, a research mentor often negotiates how much and what kinds of support are needed to allow productive engagement while simultaneously supporting student agency (Kapon, 2016). Invisible guidance may play a key role in such instances. Additionally, we added the tool recognition, where a research mentor acknowledges to the student when they notice their success, milestone, or achievement. This can be publicly or informally and is a way for a mentor to provide psychosocial support that may contribute to the student's development of a science identity (Pfund et al., 2016; Shore, 2005). In the following paragraphs, we will describe six CRM goals based on the literature. We will additionally reference any CRM tools associated with these goals as they are discussed.

One common mentoring goal is to "focus mentees on the skills and ideas needed to solve a problem" in their discipline. A primary responsibility of a research mentor is to teach students scientific skills, practices, and techniques (Feldman et al., 2008; Gafney, 2005; Kapon, 2016; Pfund et al., 2016; Shanahan et al., 2015; Shore, 2005). Findings from studies characterizing research mentoring show that mentors use specific tools to teach science practices such as scaffolding and modeling (Feldman et al., 2008, 2013; Kapon, 2016). Articles describing research mentoring often include that a mentor should be available to guide their students in the process of research and should be responsive to their student's needs in this process (Feldman et al., 2008; Gafney, 2005; Kapon, 2016; Pfund et al., 2016). However, the details of how a mentor should support students in solving problems are underspecified in the literature and it has been reported that often even research mentors have not articulated these details for themselves (Feldman et al., 2008). Studies do suggest that mentors must adapt their level of guidance to meet students' individual needs. The amount and structure of guidance are influenced by different factors such as the student, the project, or the mentor's goals (Feldman et al., 2008; Gafney, 2005).

Another mentoring goal focuses on “engaging with students collaboratively, as partners in a joint inquiry” (Brondyk & Searby, 2013; Kapon, 2016; Pfund et al., 2016; Shore, 2005; Varelas et al., 2008). Through this collaboration, the student has the opportunity to work alongside their mentor. This provides the chance to not only observe the mentor as they model expertise in a scientific process but also allows the student to be an active participant in that process. Within a joint inquiry, both student and mentor share perceived ownership of the project, both experiencing enthusiasm, engagement, and personal learning (Kapon, 2016). To support this goal, a mentor might use invisible guidance, allowing the student to remain unaware that they are receiving guidance because of the way the mentor subtly provides help in the context of working together (Feldman et al., 2013).

Research mentors also have goals that focus on their students' motivation and sense of belonging. For example, one research mentoring goal is to recognize and “acknowledge their students as scientists.” This can be done directly by recognizing actions as scientifically meaningful or implicitly through the ways that a mentor treats the student as a developing scientist. This could be through encouraging the students critical thinking, nurturing their increasing scientific self-sufficiency, and treating mentees as “junior colleagues” (Pfund et al., 2016; Shore, 2005). Another related mentoring goal is “celebrating students' research milestones.” Science is challenging and requires mentors to build their students' confidence by celebrating their scientific achievements. This is done through the tool of recognition, and by creating opportunities for the students to identify their own progress. Having a mentor who encourages their students to reflect allows them to begin to notice their accomplishments and develop a scientific identity (Pfund et al., 2016).

“Fostering collaboration among researchers” is another mentoring goal that focuses on encouraging students to work with their colleagues and the opportunities this gives them to further develop as scientists (Ayar & Yalvac, 2016; Feldman et al., 2008). Opportunities for reflection and collaboration can be achieved by having mentors create an environment with opportunities for students to work with other peer researchers on their projects or share their findings in research meetings (Feldman et al., 2008; Shore, 2005).

Finally, “creating an inclusive environment where students feel comfortable sharing their ideas” is a mentoring goal that also focuses on the social aspect of research (Pfund et al., 2016). Mentors value students feeling comfortable sharing their ideas during lab meetings or in one-on-one meetings. A mentor can provide a student with agency in selecting aspects of their own inquiry, valuing the student's individual interest, and promoting their enthusiasm (Kapon, 2016). A playful or casual atmosphere can be promoted by a mentor to allow students to be free to express ideas (Kapon, 2016). Having students feel comfortable fosters a sense of belonging in the research group and further increases their scientific identity (Pfund et al., 2016).

1.4 | Our investigation

The goal of this study is to bridge the disconnection that teachers may perceive between experiencing science practices and teaching in a science practice-based classroom. Our framework identifies aspects of research mentoring that could theoretically be translated into the classroom. We aim to understand how and why teachers may take a research mentoring approach to science practice-based instruction. Specifically, we asked:

1) *How can research mentoring be implemented as a form of science practice-based teaching? Does the CRM Framework help to describe this form of teaching?*
2) *What motivates our research subjects' approaches to science practice-based teaching?*

To answer the first question, we applied our CRM Framework as a lens of analysis for teaching in an undergraduate laboratory classroom in which groups of students were expected to conduct their own scientific inquiries. Modeling was positioned as a central scientific practice within the curriculum that students were experiencing (Hester et al., 2018). We conducted a comparative case study of two scientists as they taught undergraduate students in this setting. We selected these scientists because of their stance toward the productive implementation of science practice-based instruction. Our overall goal was to illustrate the potential utility of the CRM Framework for understanding practice-based classroom teaching. To address our second question, we continued our comparative case study of the same two scientists aiming to explain the motivations behind their approaches to instruction.

Our data set included audio recordings of each teacher as they interacted with students in the classroom and multiple interviews with the teachers throughout the semester. We utilized the stimulated recall approach in which we asked teachers to listen to and reflect on specific recorded classroom episodes (Calderhead, 1981; Shkedi, 2005). This allowed us to understand the teachers' rationale for their instructional approach. This was important for understanding how the CRM Framework could be applied to explain each teacher's enactment of practice-based instruction.

2 | METHODS

2.1 | Study context

The two teachers in this study participated in our research as they taught a one-semester introductory biology laboratory course called “Authentic Inquiry through Modeling in Biology” (AIM-Bio) (Hester et al., 2018). AIM-Bio is an undergraduate model-based inquiry introductory biology laboratory course focused on molecular and cellular biology (Hester et al., 2018). The course is a 3-h weekly laboratory section that is taught at a large, research-intensive, Hispanic-serving institution. The laboratory course is taught in conjunction with an introductory biology lecture course, though co-enrollment in the two courses is not required. The course has a large enrollment (about 1800 students per year), is required for a large array of life science majors across campus, and is also open to nonscience majors.

The course was designed to bring science practices into the classroom by explicitly using design principles drawn from the K-12 literature (Lehrer & Schauble, 2006b; Stewart et al., 2005; Wigfield & Eccles, 2000; Windschitl et al., 2008). AIM-Bio specifically asks students to participate in “cycles of modeling” (Bolger et al., 2021; Hester et al., 2018). In this cycle, students observe a puzzling biological phenomenon and generate a mechanistic model to explain what they think is going on. Next, the students design experiments to test the hypotheses and ideas in their models. Importantly, the curriculum is designed such that it is expected that a classroom of students will propose a diversity of models, with different groups of students testing different explanations for the same biological phenomenon. Finally, the students use evidence from their experiments and other groups' experiments to revise their original models. Over the course of the semester, students participate in five units which center around their participation in these cycles of modeling. Our previous work has demonstrated that legitimate scientific practices can emerge when students engage in the AIM-Bio curriculum (Bolger et al., 2021). Our previous work has also demonstrated ways that teachers can support students through a modeling cycle, illustrating the importance of how a teacher can scaffold students through modeling practices rather than pushing students toward “known” scientific ideas (Cooper et al., 2022).

TABLE 3 Teacher background information.

Subject	Position	Teaching experience	Research experience	Research mentoring
Dr. Bell	Postdoctoral Scholar	8 years (3 years as graduate TA)	15 years	6 years
Mason	Graduate Student (year 3)	1.5 years	7 years	Minimal, some technical skills support

2.2 | Case study subjects

Our study of Dr. Bell (pseudonym) emerged through our prior work exploring how the designers of the AIM-Bio curriculum navigated supporting students (Cooper et al., 2022). Through this analysis, we began to hypothesize that this teacher was using a framework that stemmed from her experiences as an active learning teacher and as a mentor in the research laboratory. To investigate this hypothesis, we chose to conduct an in-depth case study of Dr. Bell's instruction. Dr. Bell was a postdoctoral scholar at the time of data collection. She had previous experience as an active-learning instructor, conducting research, and mentoring others in a research setting (Table 3).

Our second teacher chosen for the study, Mason (pseudonym), was a part of our teacher population during our transition to large-scale implementation of the AIM-Bio curriculum for all students in the course. This involved moving to have undergraduate and graduate student TAs as the lead teachers for laboratory sections. As a part of our TA instructor population, Mason participated in a 3-h weekly PD training during his semester of instruction. The weekly training focused on supporting TAs in understanding the flow and content of activities, developing TAs' own science skills with science practices, building pedagogical strategies, and providing TAs with opportunities for metacognitive reflection. Mason was a graduate student pursuing his master's degree during the semester of data collection. As we collected observation and interview data from multiple TAs in our research study, we noticed that Mason seemed to be drawing from his experience in research when making instructional choices. Mason had some previous teaching experience in other laboratory classes. He also had many years of research experience, but little research mentoring experience in a laboratory setting. The research mentoring experience described by Mason only included teaching others technical skills in the laboratory, like using different laboratory equipment (Table 3).

2.3 | Data collection

Collected data consisted of teacher intention interviews that were conducted in Fall 2018 for Dr. Bell and Fall 2021 for Mason. Dr. Bell was interviewed at four points in the semester after the "Bacteria Growth," "Computational Cancer," "*Chlamydomonas reinhardtii* Phototaxis," and "Pathway thinking in Yeast." Mason was interviewed at two points in the semester after the "Bacteria Growth" and "*Chlamydomonas reinhardtii* Phototaxis" units. Each interview was audio-recorded and was conducted within 2 weeks of the end of each unit. We have previously described these curricular units (Hester et al., 2018).

Teacher intention interviews were designed as stimulated recall interviews (Calderhead, 1981; Shkedi, 2005). The aim of the interviews was to capture the intentions behind specific interactions that occurred with their students. We first asked the teacher to reflect on their general intentions for a specific part of the modeling cycle (i.e., model creation, experimental design, model revision) within the unit recently completed. This was followed by the stimulated-recall portion of the interviews. Author 1 listened to the in-class audio for each teacher while they supported students in the model creation, experimental design, and model revision tasks (both teachers wore microphones and were audio-recorded for all days of instruction).

She chose two audio clips, for each task, that she played for each teacher during their interview. Author 1 chose audio clips specifically to evoke reflection, primarily picking episodes that included representative approaches and interactions (after listening to each teacher holistically). The audio clips chosen lasted between 1 and 4 min (Supporting Information: Table 1). The teachers were then asked to reflect upon each audio clip that was played out loud during the interview through directed questions and additional follow-up questions by the interviewer. Mason's interviews included an additional section of two to three reflective questions in each interview to better understand his framework for teaching (Supporting Information: Table 2). Dr. Bell participated in a short, interview in Fall 2022 to ask reflective questions about her framework for teaching in this context (Supporting Information: Table 3)

2.4 | Data analysis

To address our research questions, we used a case-study approach (Tellis, 1997; Yin, 2012) focusing on the stimulated recall portions of the teacher interviews using the CRM Framework as a lens for analysis. Our analysis of Dr. Bell's case focused on three of the first four units about which she was interviewed. The "Pathway thinking in Yeast" was not included in the analysis as it was still being piloted during the semester of data collection. Analysis for Mason focused on the two interviews that were collected for him.

To address Research Question 1, the authors listened to all stimulated-recall episodes for each subject (Dr. Bell: $n = 17$ episodes over three interviews; Mason: $n = 11$ episodes over two interviews). This included analysis of the audio clip classroom interactions that occurred in the stimulated recall episodes and the teacher's reflections on each episode that occurred during the interview. We used a deductive approach with the CRM Framework as a guide for our analysis. Each author noted how tools from the CRM Framework aligned with the instructional choices during the in-class episodes played. With each episode as context, the authors then listened to the teacher's rationale for their instructional choices to determine their goals and how these aligned with goals from the CRM framework. Analytical summaries of each episode were created by author 1, immediately after meetings to facilitate a holistic understanding of each case and to document discussion around each episode that occurred in the research team. We found that all episodes analyzed included at least one goal or tool from the CRM Framework. We did not exclude goals and tools from the framework that did not appear in our analysis. Episodes chosen for inclusion in the results section were ones that included multiple goals and tools from the CRM Framework and that would highlight different aspects of the framework. Audio recordings included were transcribed verbatim. Additionally, episodes include the tone of the student or teacher when it was an important aspect of the analytical summaries. Student audio in stimulated recall episodes was only analyzed for students who consented to have their audio recorded. For episodes where students did not consent to audio recordings, we focused analysis on the teacher's words and paraphrased student contributions for context.

To address Research Question 2, the authors used the summaries created from analyzing the stimulated recall episodes in the first round of analysis for Research Question 1 to holistically investigate each case. Additionally, both researchers read and discussed verbatim transcripts of both the teachers' responses to the interview reflection questions (Mason's questions are included in Supporting Information: Table 2, and Dr. Bell's questions are included in Supporting Information: Table 3). Using the summaries and reflective responses of each teacher, both authors systematically reviewed the materials to build cases for each person that would illustrate the motivations that drove their decisions. Motivation claims were agreed upon by both authors and were chosen to describe the potential mechanisms behind differences noticed during the analysis for Research Question 1. Specifically, the authors worked to map between a single teacher's rationale for in-the-moment decisions and overall implementation decisions in the AIM-Bio curriculum.

3 | RESULTS

In the next section, we will present our findings for each of our research questions. First, we will present our findings for our Research Question 1, illustrating how the diverse CRM goals and tools can be utilized by teachers. Our findings are organized to compare across cases and will focus on three central claims: (1) Dr. Bell and Mason balance promoting student agency and scaffolding students' scientific practice, (2) Dr. Bell and Mason acknowledge students as scientists through participation in a joint inquiry, and (3) Dr. Bell prioritizes framing the epistemic aims of science for students. Subsequently, we will present findings for Research Question 2 illustrating the motivations of each teacher independently.

3.1 | Research Question 1. How can research mentoring be implemented as a form of science practice-based teaching? Does the CRM Framework help to describe this form of teaching?

3.1.1 | Dr. Bell and Mason balance promoting student agency and scaffolding students' scientific practice

Dr. Bell and Mason worked to bring their students into the practices of science. The complexities of carrying out these science practices were mirrored in the complexity of how we saw these two teachers mentoring their students. Specifically, they often balanced multiple CRM goals and tools with their students in a single interaction. In the first episode, two groups of students were asked to collaborate to develop an experiment to test their hypothesis about bacterial growth. Specifically, they were investigating why bacterial “Species E” was only able to grow in the presence of another bacterial “Species A” under growth conditions that included colominic acid in the growth medium.

Classroom Episode 1- Dr. Bell in the Bacteria Growth Unit

Dr. Bell: Okay. So, I want to-- so kind of for me, there was kind of a jump there. So, you're saying the [species] A is making something that [species] E needs to live in the medium?

Student: Yeah. That was the previous idea we thought about, but then we had an alternative hypothesis, where we wanted to say, “Hey, maybe there's actually something else going on,” and how something was actually breaking down the acid so that [species] E would survive and not get destroyed by it.

Dr. Bell:…Got it. So, you're looking to see: is there something that breaks the acid? I'm curious- was everyone interested in the abandoning your initial hypothesis? I'm curious why that hypothesis like—

Student: Well, their group actually had two to start with, so… we were cool with abandoning ours. [laughter]

Dr. Bell: To follow that one?

Student: Yeah.

Student 2: True scientists [laughter].

Dr. Bell: So- although, I will say that the colominic acid breaker test is really fast, so you could probably test both hypotheses actually… Which would be kind of cool because the more data, the merrier. So-

Student: Yeah. And in order to see the first one, we would actually take some [species] E that survived with [species] A and then put it back in the number two colominic acid [medium] and see if it actually just lives through that.

Student 3: Mm-hmm.
Dr. Bell: Got it. So, what would you expect to happen?
Student: If it actually took up something from [species] A, then the bacteria would still live.
Dr. Bell: Got it. Because it would actually have a permanent change that would let it live?
Student: Yeah

In this episode, we saw Dr. Bell flexibly thinking about her students' ideas as she guided them through participation in experimental design. The students were considering alternative hypotheses and Dr. Bell helped them to think through what they could learn by carrying out specific tests. At the beginning of this clip, Dr. Bell expressed surprise that the students picked a different direction from their original idea (lines 1–3). She then asked them clarifying questions and repeated the students' ideas back to them to make sure she understood their new idea (lines 8–10). Dr. Bell encouraged the students to test both of their ideas and discussed with the students what they might see if they carried out their proposed test (lines 16–18 and 23). During an interview, Dr. Bell explained her rationale for her actions when students changed directions from their original idea:

[the students] were like really excited and they had this idea of you know, a protein like doing something…I wanted to make sure that, that they weren't like getting beaten out of their idea, and yeah…did someone unilaterally decide that this was what they were doing or was it a honest to goodness a negotiation between the groups that this came up.

From Dr. Bell's reflective response, we can see that she was carrying out the goal of "creating an inclusive environment open to student ideas." Dr. Bell wanted all her students to have the opportunity to explore their own ideas (lines 29–33). She used the tool *recognition* to carry out this goal by articulating and valuing the students' ideas (lines 8–10). Dr. Bell emphasized the presence of multiple ideas within the group, illustrating her interest in following their thinking and recognizing the different ideas present to support their agency as idea generators. In this episode, Dr. Bell used the tool *recognition* to keep the problem space open to diverse student ideas and build an inclusive environment.

In this episode, we can also see that Dr. Bell focused on supporting her students in the scientific practice of experimental design. At the end of the episode, Dr. Bell asked the group of students to think about what results they would see if they carried out the tests they were proposing (line 23). When Dr. Bell provided her rationale for this moment, she said:

…they are going to get results, so it's almost setting them up to interpret those *results…but I think that even that, setting them up to interpret their results in light of their ideas kind of- part of like keeping the, what they are doing experimentally and what they are thinking kind of in the same bucket… kind of this idea that when you design an experiment you design it because you expect a certain outcome in light of your idea.*

Dr. Bell's reflection illustrated that her goal was to "focus students on skills and ideas needed to solve a problem," specifically, for designing a productive experiment. From her reflection, we can see that she supported her students in the process of experimental design by reminding them that it was important for the test they chose to provide results that would offer insight into their proposed model (lines 34–39). Dr. Bell helped her students connect their model to their proposed experiment by using *scaffolding* as a tool to help them to reason forward to what results they would get at the end of the experiment. Holistically, this episode illustrated Dr. Bell's coordinated use of two different CRM goals to facilitate her students' participation in science practices.

Like Dr. Bell, Mason also worked to create an inclusive environment where students would be able to engage in the science practice of experimental design. The next episode shows Mason working with a group of students, at the same point in the curriculum as the previous episode, where the students are collaboratively designing a test to explain the bacterial growth phenomena. When Mason first arrived at this group, he heard the student's proposal for three different tests they wanted to conduct. The episode below begins as the student tells Mason about the idea for their third test.

Classroom Episode 2- Mason in the Bacteria Growth Unit

Student:...And then our third idea, we weren't really sure if we could do this or not, we were gonna mix the ATCC3 [medium] and the colominic acid mediums, both of them together, and then inoculate with [species] E. Are we allowed to do that?

Mason: You can do that, and--so are getting at trying to just see if colominic acid- well, so, you tell me why you want to do that. Sorry.

Student: So, we were trying to figure out if [species] E is just, like, it doesn't have the nutrients available for [species] E, to break it down. Or if it prevents growth... For our first one [test]. And I feel like, also, it has two nutrients. So if we just take it [bacteria] out and it grows, then [inaudible]. But if we leave it [bacteria] in, it shows that it inhibits growth. I dunno. Do you think we should take it out, or just use it on its own?

Mason: Well, so what information do you get when you try to grow it in medium 2 without the colominic acid?

Student: We get that colominic acid is inhibiting growth of bacteria E. Right?

Mason: So you could find out whether colominic acid is somehow inhibiting it, but it otherwise could grow in that medium?

Student: Yeah.

...

Mason: And then the other idea, I think you were saying, is put ATCC3 with colominic acid. Put [species] E in that.

Student: Yeah.

Mason: So what information does that give you, then?

Student: So we know [species] E can grow in the ATTC3 [medium], we know that ATCC3 [medium] has nutrients that [species] E can use. So if you were to put it in with colominic acid, that would show us if colominic acid is acting like some sort of toxin and killing it off, or if it just, it doesn't have the nutrients that it needs.

Mason: Awesome. So those are kind of like two different perspectives on the same idea. Cool, yeah. I really like that.

After Mason heard all three test ideas the group had, he started to tell the students what he thought their hypothesis might be but stopped himself partway and instead asked them to tell him what their hypothesis was (lines 43–44). As the students talked through their idea with Mason, they moved back to their tests and asked Mason what he thought they should do. We can see that Mason's response to this question was to ask them what they would learn from doing each test (lines 51–52 and 61). During his interview, Mason explained his rationale for starting to tell the students what he thought their idea was and then stopping part-way and instead asking them what they were thinking (lines 43–44):

68 *So I might think that I know what they're saying or what they're talking about when I*
69 *start, and then I realize I better have them explain in detail. And I also- I don't want*
70 *to have, I guess, my own sort of background preconceived notions about why all these*
71 *different interacting elements do color my, my questions from them. So, yeah.*

From Mason's reflective response, we can see that he carried out the goal of "creating an inclusive environment open to student ideas" by valuing his student's ideas. From his reflective response, we can see that Mason had a sense of where he thought the students were going, in terms of the direction of their idea, but he did not want his own ideas to influence how he guided them (lines 68–71). He wanted to support his students' epistemic agency by not taking away their opportunities to come up with their idea. In the in-class episode, this moment illustrated Mason's use of the tool *articulation* when he asked the students to state their idea (lines 43–44). Similar to Dr. Bell, Mason also used the tool *recognition* to carry out this goal. He implemented this tool at the end of the interaction, on lines 66–67, where he emphasized and encouraged his students that they had thought through their idea and that it was productive.

In this second episode, we also can see how Mason focused on supporting his students in the scientific practice of experimental design. At multiple points in this episode, we saw Mason ask the students to think about what information they would know if they carried out the tests they were proposing (lines 51–52 and 61). When Mason explained his rationale for this line of questioning, he said:

72 *Yeah, I mean, so that's just like for me, that's just like a basic part of my thought*
73 *process in research… So, um, just to make things clear, I find it useful to like, really*
74 *open up, like each step of a process or each element of an idea. And so in trying to*
75 *help students with stuff, you know, lab is like a chaotic place. So trying to give them*
76 *a chance to open up each element of an idea to make sure they know what they mean.*

Like Dr. Bell, Mason also had the goal to "focus students on skills and ideas needed to solve a problem" to support them in productively designing an experiment. From Mason's reflection, we can see that this approach was connected to his own ideas about how he conducts research (lines 72–73). Specifically, he wanted the students to think through the different components of their idea, which is an approach he used when he is carrying out his own inquiries in the laboratory. He used the tools of *scaffolding* and *articulation* to support his students in the practice of experimental design. From lines 51–52 and 61 in the in-class episode, we can see that he framed his scaffold around asking his students to articulate what information they would learn if they carried out each of these tests. This focused his students to not just reason forward to what results they predicted they would see, but also on what these results might mean. Similarly to Dr. Bell, Mason used these two goals as an interwoven practice to support his students in participation in science practices.

3.1.2 | Dr. Bell and Mason acknowledge students as scientists through participation in a joint inquiry

As we saw in the above section, these instructors balanced multiple goals and tools when interacting with their students. In the next examples, we will illustrate that Dr. Bell and Mason had the goals "acknowledge students as scientists" and "engage collaboratively in a joint inquiry with students." Both teachers acknowledged their students as scientists by participating in the science practice alongside their students in a joint inquiry. Interestingly, the tools used to carry out these goals differed for our two teachers. In our next episode, the students were asked to design a drug treatment for cancer using a computational model of a tumor. At the beginning of this episode, we will see that this group was making sense of an interesting result they found from running their drug trial.

Classroom Episode 3- Dr. Bell in the Computational Cancer Unit

Dr. Bell: Alright, so I'm curious, have you guys figured out your weird switching over thing?
Student 1: Um- we- [laughter] okay so like we were saying that before we reached this mark, that the cells with mutations were the ones that were surviving and that were competing with the ones that didn't have mutations… this is where they started to break off and the ones with mutations were dying so quickly that they couldn't reproduce and so the ones without mutations were actually the ones surviving and getting more oxygen and nutrients.
Dr. Bell: Cool
Student 1: That's it- I think that's what we came up with.
Dr. Bell: That makes sense. That's cool, one thing I was just thinking about- I'm curious. I don't want to derail your presentation- but if you finish your presentation and have a few minutes before you present, I want to know if you always get this happening when you run this? How consistent is this result? Cause there is randomness, right-
Student 1: Right
Dr. Bell: -cause the mutations are actually random. I wonder if this is just a really lucky patient where all of their tumor wound up-
Student 1: Oh yeah
Dr. Bell: Or if like every time you treat this way you are going to like get all your cells
Student 1: So are you saying we should run it at like two--a couple of times to like see-
Dr. Bell: Yeah, I would go ahead and run it again just to see, because I am really curious, and you could even run it like here too to see if sometimes will you actually get a green tumor or yeah like is it a critical point or just random different things playing out cause-
Student 1: Right
Dr. Bell: -I don't know.
Student 1: That's really interesting. Alright.

In this episode, Dr. Bell engaged in sense-making with her students about the interesting results they found. After Dr. Bell heard the group's interpretation of their findings, she expressed enthusiasm about their ideas (lines 87 and 100–101). She suggested the group run additional trials to further explore their result (lines 100–103). Dr. Bell's rationale for her goals in this episode focused on her intention of encouraging student curiosity:

So with this group- really is it was kind of a feeding into their enthusiasm and my enthusiasm is that they got a cool result and just kind of- I wanted to follow up with them and kind of reaffirm again like this is a cool result and also kind of encourage them to go further…because they thought it was cool and to give them kind of a couple of different things to think about that could be going on because they had some- as you heard, some really interesting ideas for how to explain it but I was kind of throwing them an additional question because I thought they did a really good job of answering kind of just the basic initial question and I was like well, what about this additional question?

From Dr. Bell's reflective response, we can see that she had the goal of "engaging collaboratively in a joint inquiry with students." From her reflection, Dr. Bell admitted her own enthusiasm and interest in her students' unexpected findings (lines 107–108). She encouraged them to further investigate this idea to possibly reveal data that she and the students would both value (lines 108–115). She used the tool *exploration* to push students to expand their investigation. Dr. Bell encouraged the group's curiosity in the findings, providing support for ways they could further pursue their line of thinking (lines 87–103 and 100–103).

Dr. Bell's implementation of "engaging collaboratively in a joint inquiry with students" in this case worked as an approach for another goal, "acknowledge her students as scientists." Her reflection revealed her goal of also pushing her students to engage fully in the science practice of explanation building. She was excited about the interesting result her students got and wanted to encourage her students that they found something exciting (lines 107–110). Even though the students had completed the classroom task of running their experiment and interpreting their data, Dr. Bell provided the additional challenge of a further investigation, like one may do if they are conducting research on a novel system (lines 113–115). Through her collaboration with the students and excitement about their results in the in-class audio (lines 87–103), she showed her students that she valued their ideas and emphasized their scientific contribution.

Like Dr. Bell, Mason also carried out the goals "acknowledge students as scientists" and "engage collaboratively in a joint inquiry with students" simultaneously. The next episode shows Mason helping a group of students design their experiments during the *Chlamydomonas reinhardtii* Phototaxis unit. Specifically, they were investigating the mechanism of how *Chlamydomonas reinhardtii* organisms swim in response to light. The episode begins with Mason hearing the student's idea to conduct a choice test of different colored filters that *Chlamydomonas reinhardtii* will swim toward. In this episode, student responses are paraphrased as the group of students did not consent to audio recordings.

Classroom Episode 4- Mason in the Chlamydomonas reinhardtii Phototaxis Unit

Student: [describes unique experiment of a choice test with colored filters and controls]

Mason: Well, how about this before we get into the mechanism- or the methods rather, of how you're going to do that experiment, which is interesting. Let's talk about what your hypothesis is that you'd be testing. So like, how does this fit into a model of phototaxis?

Student: [state hypothesis about colors influencing photosynthesis]

Mason: OK. Oh, interesting [tone of curiosity]. So- [pause] so they prefer certain wavelengths for photosynthesis. And so you expect they will go to filter colors that they're better at synthesizing in?

Student: [agree, explaining preference for colors]

Mason: Yeah, that is interesting. [pause] So. [pause] So that would tell you whether they have- [pause]. Ok, so your hypothesis then would actually have more little sub-hypotheses, right? So not only do they photosynthesize, better or worse in different light, but then can they actually sort of see color.

Student: [agree]

In this episode, Mason appeared to be genuinely interested in his student's scientific work as he engaged with them to understand their idea. After Mason heard the student's idea for doing a choice test (lines 116–117), he asked them to tell him what their hypothesis was (lines 118–121). Mason displayed curiosity when he asked to hear more about their thinking and followed up by asking questions about their expected results (lines 123–125). Throughout the episode, Mason processed the student's idea, evidenced by his tone of curiosity and frequent pauses. Mason's rationale illustrated his own interest in helping the student figure out a way to pursue their idea:

I really liked his idea, basically trying to set up like a choice test for Chlamydomonas…so I really wanted him to be able to figure out a way to do it. But I felt like no matter what, it was going to have to deviate from like the available tools. And he'd be basically like designing a new tool, which I wasn't like 100 percent against…I don't know what it would be, but something. So I wanted them to be able to do this idea because it was an interesting one and he seemed attached to it… I probably should have just pushed him away from this idea earlier. But I was a little attached to it too, and I was like, "Oh man. It'd be really cool if you could do that."

From Mason's reflective response, we can see that he had the goal of "engaging collaboratively in a joint inquiry with students." Mason's reflection revealed that he was genuinely curious about his student's ideas and that he wanted to work with his student to think through the specifics of their idea (lines 132–133). He reflected on the fact that he maybe should have pushed the students away from their idea but he, the teacher, was attached to the student's ideas as well (lines 136–140). He clearly believed that his students were capable of doing the work here and so he wanted to support them in pursuing their idea, even helping them create new tools if needed.

Like Dr. Bell, Mason used the goal of "engaging collaboratively in a joint inquiry with students" to carry out the goal of "acknowledging students as scientists." From his reflective response, he talked about wanting to honor the student's ideas and help him find a way to test the idea, even though he was unsure about possible available tools that aligned (lines 136–138). Across the episode (lines 123–125 and 127–130), we saw that Mason was curious about the student's ideas and took the time to ask the student questions to better process their thinking. We saw Mason used the tool *recognition* to carry out this goal. Through his interest and excitement for the student's idea, Mason emphasized how he valued their thinking. Mason collaborated with his students in a joint inquiry, which in turn, allowed him to acknowledge them as scientists.

3.1.3 | Dr. Bell prioritizes framing the epistemic aims of science for students

Dr. Bell worked to build a shared understanding of epistemic aims in her classroom. She focused on framing the goal of the current task of building evidence-based explanations and redirecting this framing for students when needed. The episode we present next occurred after the students had conducted their experiments in the bacterial growth unit. The students collected and analyzed their data and shared their findings with other groups in the classroom. The group in the following episode was working to draw a revised model that incorporated the different pieces of data available to explain the biological phenomena.

Classroom Episode 5- Dr. Bell in the Bacteria Growth Unit

Student 1: I have a question. So, from what we were listening to [when talking with other groups], [species] A breaks the colominic acid and allows [species] E to survive. Does it need to break the colominic acid when it's on its own to survive? Does that-?
Dr. Bell: Did anybody grow [species] A without colominic acid? I'm trying to-
Student 1: Yeah. We did that and it didn't survive.
Dr. Bell: it didn't grow.
Student 1: But does it need colominic acid? And does it need to break it down to survive? Or does it not need to break down the colominic acid-
Student 2: Well, it survived right.
[pause]

Dr. Bell: So, the answer is I don't know. [student 1 laugh with frustrated tone]. The data are the data. So, what we kind of know is just what happened in these different results.
Student 1: Okay.
Dr. Bell: So that seems- I guess. What do you think?
Student 1: I was thinking that it [species A] did break it down for itself. Just- I don't even know. Like. Just cause if [species] E needed it broken down-
Dr. Bell: Yeah
Student 1: -but [species] E couldn't break it down by itself then-
Student 3: [species] E metabolize it somehow and uses it
Dr. Bell: [pause] Yeah. Cool.

Dr. Bell's mentoring approach here was to reframe the goal of this task for her students. The student group was asking Dr. Bell questions about the “answer” to the phenomena and seeking validation from their teacher about claims from the data (lines 141–144). Dr. Bell ultimately told the students that she did not know the answer to their question and that the task was for them to consider the data that was available to come up with a plausible explanation (lines 152–154). The students appeared to be unsatisfied with her response, based on their frustrated laughter. She asked the students to tell her what they thought seemed plausible and left them to continue reasoning about their ideas (line 156). During her interview, Dr. Bell explained her rationale for this episode:

Intentions with this group. So the interaction starts off with them essentially posing it as “we have this thing that we think is going on, is it the right answer?” And so my initial hope is to kind of flip it around and be like, that's not the point. The point here is to come up with something plausible given what we know, not to come up with the right answer. And so I lied a little bit [laugh] and said that I didn't know. But I think it mostly did the trick. Like to just turn it back on them and say “I don't know what's going on, what do you think could be going on?” so that was really my- a huge part of that interaction was just trying to make that switch around.

From her reflection, Dr. Bell had the goal of “acknowledging her students as scientists” by positioning them as epistemic agents. In her reflection, we can see she wanted to move her students away from seeking a “right answer” and reframed the task as building explanations based on evidence (lines 164–167). She wanted to push her students to engage in the scientific enterprise of building evidence-based explanations. Dr. Bell used the tool of *invisible guidance* in this episode. She first pointed the group in the direction of data that may help them think about an answer to their question (line 145). When the students did not take up this line of thinking, she then moved to reframe the task for the students (lines 152–154) and then left the group to continue thinking on their own. She provided some guidance by pointing them in a productive direction but ultimately leaves them to allow the group to do this sense-making process for themselves. She did not stay and walk the students through data sense-making or reasoning about plausible explanations with them. By avoiding being overly directive or doing the work for the students, Dr. Bell used guidance that may have been less visible or obvious to her students. Ultimately, Dr. Bell was working to build a shared understanding of the epistemic aim of science for her students in this episode. As one of the designers of this curriculum, she is aware of the desired epistemic aims for students and worked to bring these into her teaching.

Through our investigation of Research Question 1, we uncovered that both teachers' approaches to science practice-based teaching could be described by the CRM Framework (Table 4). We saw evidence of all the goals and tools being used, except for the goal “foster collaboration between student researchers” and the tool *reflection*. We also noticed that there were differences in the ways the two teachers approached supporting their students, which we will describe in the next section.

TABLE 4 Overview of CRM Framework case application.

	Teacher	CRM goal	CRM Tool
Dr. Bell and Mason balance mentoring student agency and scaffolding students' scientific practice.	Dr. Bell	"Create an inclusive environment open to student ideas"	Recognition
		"Focus students on skills and ideas needed to solve a problem"	Scaffolding
	Mason	"Create an inclusive environment open to student ideas"	Recognition and articulation
		"Focus students on skills and ideas needed to solve a problem"	Scaffolding and articulation
Dr. Bell and Mason acknowledge students as scientists through participation in a joint inquiry.	Dr. Bell	"Engage collaboratively in a joint inquiry with students"	Exploration
		"Acknowledge students as scientists"	
	Mason	"Engage collaboratively in a joint inquiry with students"	Recognition
		"Acknowledge students as scientists"	
Dr. Bell prioritizes framing the epistemic aims of science for her students.	Dr. Bell	"Acknowledge students as scientists"	Invisible guidance

3.2 | Research Question 2 What motivates our research subjects' approaches to science practice-based teaching?

Dr. Bell and Mason have similar goals, but their own unique experiences led to different motivations behind their classroom research mentoring approaches. In the next section, we will describe the aspects that motivate each teacher's approach to teaching in this context.

3.2.1 | Mason's previous experience in science influences the ways he approaches teaching

Mason's motivation seemed to stem from his own experience as a student and a scientist (Figure 1). His previous experiences provided intuition for how to support his students as scientists. Through enacting science practice-based teaching, Mason further articulated his own ideas about what science is (Figure 1, double sided arrow). In this section, we will provide evidence for this model.

Mason was motivated to create a classroom experience that was different from his own student experience. At the end of Mason's first interview, he reflected on the main goals he was hoping to accomplish while teaching his students in this context:

...in my own experience, moving from undergrad into research situations, there's really not a lot of like formal education on like how to do this stuff. I mean, I feel like there's attempts made at it, but a lot of them are kind of crude and they're like in early education. And yeah, at least in my experience, you know, coming up with and carrying out inquiries. You know, [is] deficient, I guess...to me, that seems like the

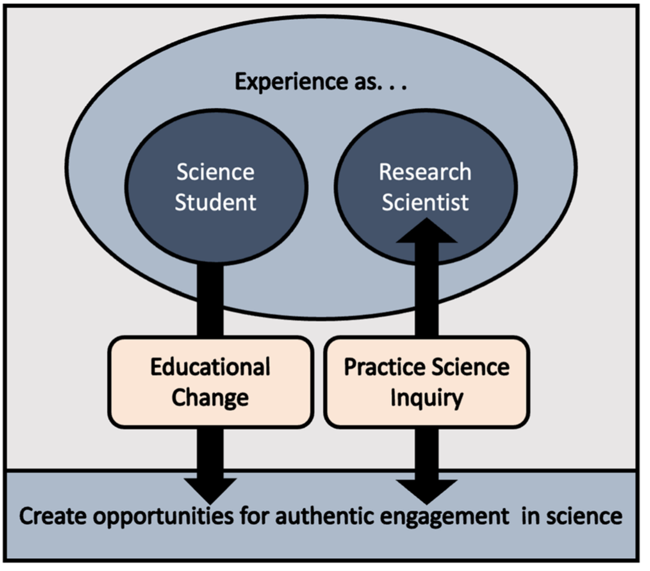

FIGURE 1 Mason's motivations for supporting student authentic engagement in science. The diagram depicts the major influence of Mason's experience as both a science student and research scientist on how he supports his students' authentic engagement in science practices.

176 *most important thing to do with this kind of a lab is to get people comfortable with the*
177 *existence of the unknown and then making attempts at chipping away at it.*

Mason's own experience as a student was a strong motivator for his approach to teaching (Figure 1, top circles). Here he reflected on the fact that his own classes, in his view, did not prepare him to be a scientist conducting research. He deeply cares about this problem and saw this class as an opportunity to begin remedying the issue. Below, he continued to reflect on his main goals for teaching his students:

178 *So I guess part of the- the vibe that I've gotten all along is sort of a more, I guess,*
179 *process over content…it seems like, ideally, like a student who was like most*
180 *prepared by their previous education, coming into the class would benefit a lot from*
181 *like understanding all the background stuff and being able to progress through, like*
182 *doing intentional experiments and inquiry. A lot of students coming in don't really*
183 *seem quite prepared for that because they're struggling enough just with like kind of*
184 *carrying out the act of like confronting, not knowing something and trying to find out*
185 *about it without someone being there to tell you what's true. And so to me, that's,*
186 *that's the process- focusing on getting them to be able to do that process. They can fill*
187 *in all of the little tinkery details later about, you know, proteins and they will because*
188 *we're saturated in that information all the time and all the other classes that we take.*
189 *But this is the one place where you have a chance to practice this sort of inquiry.*

Here, Mason articulated his goal of engaging students in the process of science (lines 178–179) (Figure 1, bottom box). He contrasted this with other types of classes where the focus is on science content rather than the processes of carrying out science practices. He understood that the process of science is hard for his students, especially dealing with uncertainty and not having a "right" answer. He clearly valued his classroom space as "the one place" where his students have a chance to carry out inquiries and engage in science practices (lines 188–189) (Figure 1, left orange box). Mason's personal experience of carrying out science practices as a researcher appeared in some of his stimulated-recall reflections (Figure 1, top circles). The next example illustrates one moment where he reflects on his own experience of designing controls:

… I'm talking about positive and negative controls. For me, it's always been like a little bit intimidating. Like, I'm like, what the heck is a positive control? And I have to like, really think about it, and it kind of detracts a little bit from whatever I'm trying to focus on when really, like the important thing is like, well what I said is like, how do I know that I've done the experiment right?…

Mason's reflection about his own experience with controls shows how thinking about them is not very intuitive. The words positive and negative controls are something that he reacted to specifically here, illustrating his own evolution in understanding these aspects and how they are used (lines 193–194). Below, Mason continued to reflect about controls:

…a lot of what we learn in sort of science education, at least in my experience, is very formulaic where you're like, all right, you create your hypothesis and blah blah. And somewhere in there, there will be that you have controls. And I think you can- you can sort of algorithmically carry out this like caricature of science without actually knowing what you're doing or why. And I [have] like been in that position and done that. And so to ask someone to think about like a way to ensure that what they did was correct. They think about that. But if you tell someone create a control, it's you know, it's, it's in a way specific because you've asked them to do a particular scientific thing. And it's also vague to me.

In this next part of Mason's reflection, we gain further insight into his own experience with taking science classes. He reflected on the systemic, linear way that science is often represented in classes and how that allows students to carry out science without *understanding* science. Mason's experience carrying out science in this simplified way in his own classes seemed to be critical in motivating his approach to move away from this in his own teaching. With this example specifically, Mason's approach when helping his students was to not tell his students to have controls but to instead ask them to think about the experimental conditions they could use that would help them know that something did not go wrong in their experiment. His own knowledge and experience engaging with science through research motivated him to find ways to bring this authenticity into his own classroom (Figure 1, right orange box).

Overall, Mason's experience in his science classes as a student and carrying out his own inquiries through research motivated his classroom research mentoring approach (Figure 1). The above examples illustrated how Mason valued his students' engagement with science. He was motivated by wanting to remedy this deficit from his own student experience and wanting his students to *understand* science. Mason's motivations presented here provide further insight into his teaching approach used with his students. Through our analysis of Research Question 1, we saw that Mason had goals to support his student's agency and identity as scientists ("create an inclusive environment open to students' ideas" and "acknowledge students as scientists"). His motivations here aligned with these goals as we can see that he cared deeply about creating an experience for his students that was different from his own. He wanted to create opportunities for his students to develop as scientists at early points in their academic careers and in the classroom. Additionally, Mason also had the goal to support his students in engaging in science practices ("focus students on the skills and ideas needed to solve a problem" and "engage collaboratively in a joint inquiry with students"). Mason clearly articulated the ways he used his own experience as a researcher and scientist to provide him with an intuitive direction for ways to support his students in ways that are like that of a scientist.

3.2.2 | Dr. Bell's science epistemology motivates her goals for student learning and student engagement

We present Figure 2 as a model to explain Dr. Bell's motivations for engaging students in science practices. We found Dr. Bell's approach to teaching was that of a science mentor in that her primary motivations related to our three functions of mentoring. Specifically, Dr. Bell was motivated to build a shared understanding of epistemic aims (by supporting her students in building evidence-based explanations), to support learners in the productive use of science practices (treating students as scientists), and to motivate learner engagement with science practices (promoting student agency). Our findings also reveal the interconnected way that Dr. Bell navigated these three components (arrows). In this section we will provide evidence from Dr. Bell's interviews to support this model.

Throughout the semester, Dr. Bell worked to support her students in building evidence-based explanations. In an earlier episode (lines 141–162), we saw Dr. Bell wanted to support her students by building a shared understanding of the enterprise of science. In this episode specifically, we saw Dr. Bell work to move her students away from seeking a "right answer" and instead she reframed the task for her students of building evidence-based explanations (Figure 2, green box). In Dr. Bell's exit interview, she was asked to reflect on the main goals she was hoping to accomplish:

204 *So, I think a big thing that really drives the way that I interact with the students is*
205 *that I want us to be doing it, I want us to be building evidence-based explanations.*
206 *And my hope is that they will become increasingly aware that is actually what we are*
207 *doing…*

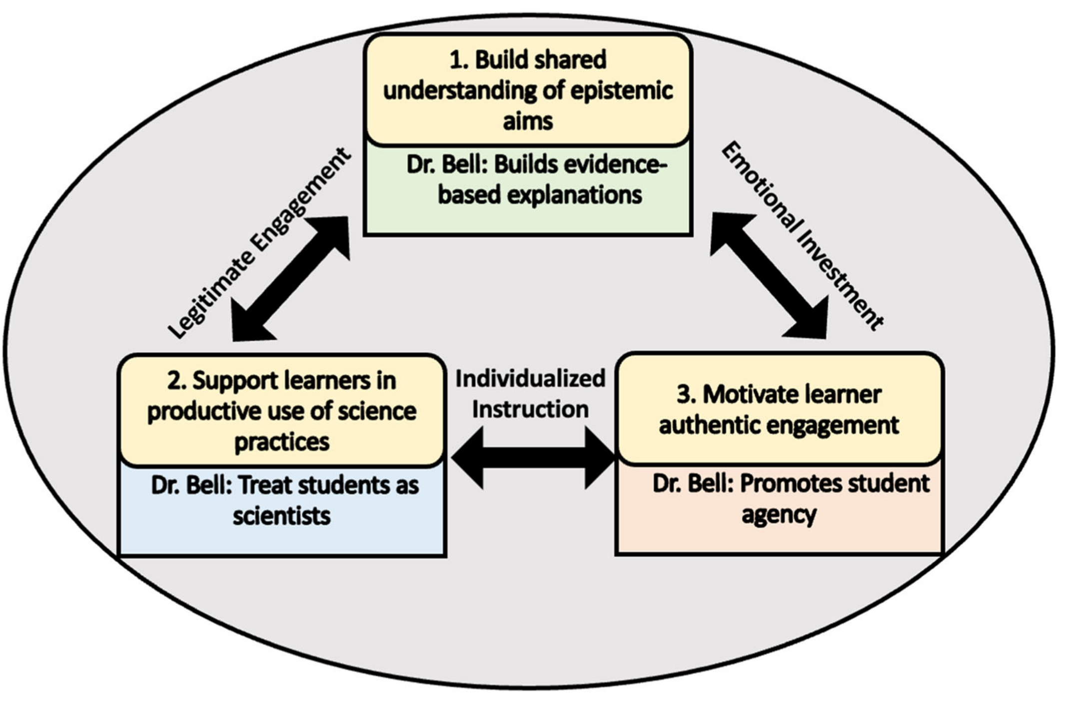

FIGURE 2 Dr. Bell's motivation to develop student science understanding connects to three functions of mentoring. Dr. Bell focuses her students on building evidence-based explanations as a shared understanding of epistemic aims, treating her students as scientists to support productive engagement in science practices, and promoting student agency to motivate their authentic engagement. She carries out these three functions of mentoring as an interconnected practice in order to engage her students in science practices.

Dr. Bell was driven to create a classroom where her students were conducting science. She was strongly motivated by the need to have her students engage in science practices, as she wanted them to be "doing it" (line 205). Along with doing science, she wanted her students to also *realize* they are doing science and begin to *understand* what science is (lines 206–207). The next example illustrates one moment where Dr. Bell reflected on one of her student group's growth across the semester during one of her stimulated recall reflections:

208 *This was kind of one of the first times, for that particular group, that I just saw them*
209 *really genuinely seem to be like interested and really want to try to explain, not*
210 *because it had been a task assigned to them but because they were actually curious*
211 *about what was going on.*

Dr. Bell's reflection about this group showed her ongoing commitment to having her students build explanations. This moment illustrated some of the tensions Dr. Bell battled as she navigated moving her students away from doing school tasks and toward engagement with science practices (lines 210–211). Dr. Bell cared about all her students, often referencing their individual experiences and their individual journey toward understanding the epistemic aims of science. Below, she continued to reflect on her main goals while teaching her students in her exit interview:

212 *…I really want students to be excited about the fact that they are learning in this new*
213 *way where they are actually learning through investigation and inquiry…that they*
214 *are building the knowledge through the inquiry…And so it's really important that*
215 *students both- do own it and that they recognize and feel like they own it…*

Dr. Bell believed that her students learn through their active engagement in carrying out an inquiry about their own ideas. She wanted her students to have ownership over their ideas but also recognize that they do have ideas (line 215) (Figure 2, orange box). Additionally, Dr. Bell emphasized that her students needed to have agency to productively build their own evidence-based explanations (Figure 2, arrow between green and orange boxes). In her next reflection, she emphasized the importance of her students' emotional investment as a critical part of authentic engagement:

216 *…when you really start talking about authenticity, it's impossible to separate it from*
217 *the way the people who are doing it are feeling. And so- And so I think that is part of*
218 *again, why controversy and diversity of ideas and diversity of data- all of these,*
219 *basically, signals of agency, are important because they actually have the potential to*
220 *make the people doing it actually feel it. Like to be curious, to want to seek out other*
221 *people's ideas, have reasons to collaborate, to experience a genuine need to know but*
222 *then also have things they know how to do to actually satisfy that.*

Dr. Bell wanted her students to have a need to engage in science practices through their emotional investment (lines 220–222). Student agency drives an authentic need for their engagement with science practices and moves them away from just completing "classroom tasks." However, supporting students effectively can be challenging as there is a balance needed between providing guidance and promoting agency. Below, she continued to reflect on her main goals for students in her exit interview:

223 *…So something that can actually be a challenge and definitely dictates some of the*
224 *ways that I interact with them is that I don't want to step on [student agency]. And so*
225 *I think a goal is just to not over insert myself into the thinking process but to be there*
226 *to kind of give them the support and nudges that they need to do it productively.*

Dr. Bell was motivated to support her students with the productive engagement of science practices (Figure 2, blue box). She viewed her role as a mentor who provides guidance but also makes sure her students are the ones participating in the practices (lines 225–226). She was often found individualizing her instruction to meet the needs of each group to provide helpful guidance based on their specific ideas (lines 1–28 and 77–106) (Figure 2, arrow between orange and blue boxes). This also included consideration of how her teaching choices could affect her students' legitimate engagement in the shared practice of building evidence-based explanations (Figure 2, arrow between blue and green box).

Dr. Bell was motivated to have her students build evidence-based explanations, support her student's engagement in science practices, and promote student agency. Each of these motivators are directly interwoven and connected to how Dr. Bell thought about her approach to supporting her students (Figure 2, arrows). Like Mason, Dr. Bell's motivations align with our findings for Research Question 1. She clearly sought to support her student's agency and ownership in the classroom ("create an inclusive environment open to students' ideas" and "acknowledge students as scientists"). She was greatly motivated by her understanding of what is required for their engagement and student agency, where their investment is critical. Additionally, she sought to support her students' engagement in science practices ("focus students on the skills and ideas needed to solve a problem" and "engage collaboratively in a joint inquiry with students"). Dr. Bell's goal of the class working together to build an evidence-based explanation of the biological phenomena was a key motivator to many of the decisions she made in how she approached supporting her students.

4 | DISCUSSION

This study proposes the CRM Framework as a novel lens for thinking about science practice-based instruction. Our results highlight the utility of this framework for instructional analysis. The CRM Framework explained much of what our subjects did in the classroom, as they both had personal conceptions of laboratory teaching that aligned with research mentoring. Analysis revealed that both teachers sought to develop their students' understanding of an epistemology of science. The position and experience of each teacher influenced their implementation of this primary goal. Mason's position as a graduate TA who was a novice teacher and experienced research scientist and Dr. Bell's position as a postdoctoral researcher with previous experience as a teacher, curriculum designer, and scientist were important. In Mason's case, he was learning ways of implementing research mentoring from his previous experiences as a student and ongoing experience developing as a scientist (Figure 1). Dr. Bell had a well-developed research mentoring approach and intentional framework for carrying out her goals (Figure 2). The CRM Framework worked to describe the approach of these very different teachers because they both shared the same primary motivation of mentoring their students in science.

The use of both our CRM Framework and stimulated recall approach was essential for understanding the complexity of science practice-based teaching. This method allowed us to uncover the in-the-moment rationale behind teaching choices. The literature investigating teacher reasoning focuses primarily on dissecting individual aspects of instruction, such as teaching beliefs (Ferrare, 2019; Harwood et al., 2006; Männikkö & Husu, 2019; Ravitz et al., 2000; Stuart & Thurlow, 2000) or classroom actions (Chin, 2007; Ginath & Southerland, 2019; Velasco et al., 2016). These approaches can provide essential insight, but more information is still needed to connect the different aspects that makeup teacher reasoning. Teacher intentions or the rationale behind teaching decisions is often overlooked through these approaches. Our previous work highlights the usefulness of investigating teacher-in-the-moment intentions to understand teacher reasoning (Cooper et al., 2022). The current study builds upon this approach through the use of stimulated recall, which allowed for in-depth case studies of science practice-based instruction. Analysis of Dr. Bell and Mason's cases provided the in-the-moment rationale for how aspects of research mentoring connect to more generalizable aspects of teaching (e.g., scaffolding or modeling). We believe that understanding the rationale between teaching choices is a critical aspect that requires further investigation across contexts as we continue to build pedagogical practices for science practice-based instruction.

4.1 | Negotiating the role of the teacher in science practice-based teaching

There are many components needed for successful practice-based instruction, two important ones being the curriculum and the teacher. The curriculum provides the needed structure through activity design and framing the context necessary for science practices to emerge. However, a well-designed curriculum alone is unlikely to produce desired student outcomes. Teacher implementation is key to translating the overarching goals of the curriculum to in-the-moment framing of activities. The teacher holds an essential role in helping to build a community that allows productive student engagement. However, teacher implementation of science practices is a well-documented challenge (Manz & Suárez, 2018; Varelas et al., 2005; Watkins & Manz, 2022). We argue that successful practice-based instruction requires teachers to rethink their role in the classroom. The routines, roles, and responsibilities of a teacher in a traditional classroom conflict with those of a science practice-based community (Crawford, 2007; Ford & Wargo, 2007; Rudolph, 2008; Windschitl & Thompson, 2006; Windschitl et al., 2008). Specifically, a teacher's core identity is often not aligned with reform-based pedagogy (Luehmann, 2007). Changing instructional practices requires teachers to confront their existing teaching beliefs and address internal or external conflicts (Anderson, 1996; Johnson, 2006; Luehmann, 2007). Teacher educators play a part in supporting novice teachers to negotiate what their role in the classroom is and to develop an inquiry-oriented teacher identity. We propose that one productive approach could be centered on research mentoring, where our CRM Framework can serve as a tool for thinking about this role. A key reason that teachers in our study engaged in classroom research mentoring was their value of science. Science values encompass how one relates to the objectives of a scientific community (Estrada et al., 2011). For example, if one has a strong value for science, they will identify as someone who thinks it is important to conduct research to build the world's scientific knowledge, discover new things, discuss new theories and ideas with other scientists, and solve the world's challenges through research (Estrada et al., 2011). We propose that a *value* for science is beneficial in translating research mentoring into a classroom pedagogical approach. Our two teachers both valued science and this was what allowed them to operate within the CRM Framework. They carried out instruction differently and with different levels of expertise, but they shared this value of science and epistemology of science. We believe a value for science is a key first step in translating views about science to teaching practices, especially in considering how one develops a new teaching identity for this type of instruction.

Previous efforts have shown there can be a disconnection between teacher understanding of science and how they bring science practices into their classroom (Brew, 2010; Malachowski et al., 2020; Varelas et al., 2005). PD strategies have centered on K-12 teachers participating in short-term research experiences to deepen their experience with science (Bismack et al., 2022; Davidson & Hughes, 2018; Schwartz et al., 2004; Varelas et al., 2005). These experiences can help to develop an understanding of the NOS but do not necessarily translate into pedagogical performance (Varelas et al., 2005; Bismack et al., 2022). We hypothesize that teachers in these situations may have not yet fully developed a *value for science*. Short-term research experiences are a necessary first step to begin helping teachers understand what science is but may be insufficient to fully develop a scientific epistemology. Additional PD resources that build on these experiences are needed. Previous work has shown that successful PD programs specifically aim to support teachers in rethinking their teaching and learning beliefs and in developing classroom strategies for implementing new forms of science instruction (Johnson, 2006; Reiser et al., 2017). We suggest that a similar approach could be used to develop a teacher's value for science through activities that support teacher beliefs around the epistemic aims of science.

Having a framework for science and a value for science is an important first step to science practice-based instruction, but tools for implementation are also necessary. Our study demonstrates how our two teachers had a strong science framework that drove their instructional choices, but Dr. Bell had a more diverse toolset for implementing practice-based instruction compared with Mason. Even those with a well-developed value for science, such as practicing scientists, can experience tension between directing students in their research laboratory and teaching undergraduate science classes (Brew, 2010; Malachowski et al., 2020). It is evident that someone can have a fully developed view of what science is but not know how to *teach* science. Well-documented challenges in research mentoring point to the mixed quality and effectiveness of mentoring in practice, further illustrating the complexity of appropriately supporting science newcomers in any setting (Allen, 2003; Kram, 1983; Limeri et al., 2019a; Tuma et al., 2021). However, there is also evidence of increased understanding of the epistemology of science from individuals who are engaged in both research and teaching (Davidson & Hughes, 2018; Feldon et al., 2011; Reid & Gardner, 2020). We believe that the CRM Framework can help teachers articulate mentoring approaches to help with teaching both in a laboratory classroom and in the practicing research laboratory. Beginning researchers, such as graduate TAs, could also benefit from the chance to reflect on how they are building a framework for supporting their students and research mentees to become scientists.

4.2 | The ways Dr. Bell and Mason applied the three functions of research mentoring in the classroom

Our results highlighted the different ways that our two teachers translated the three functions of mentoring into a classroom setting. Both teachers worked to *build a shared understanding of epistemic aims*, by providing framing for building evidence-based explanations and inviting their students to join in the shared practice. Dr. Bell and Mason both worked to move their teaching away from traditional views of classroom science and worked to develop their students' *understanding* of science through their engagement. Additionally, they both provided individualized instruction to *support learners in the productive use of science practices*. Dr. Bell and Mason viewed their student engagement in scientific practices as an iterative process, allowing flexibility and growth in how they guided and worked with their students. Finally, both teachers focused on supporting their students through the emotional aspects of science and *motivating learner engagement with science practices*. They genuinely valued their students' ideas, often getting excited along with their students in their accomplishments. Importantly, the connections between these three functions of mentoring should not be overlooked. Dr. Bell and Mason used these three functions of mentoring as an interwoven practice, providing initial evidence of how these components influence each other to allow for successful mentoring.

4.3 | Application of CRM Framework

The CRM Framework has potentially useful applications for both research and teacher PD. Considering the practice turn that is taking place in both K-12 and undergraduate education, there is a need to understand how teachers think about science practice-based instruction. The CRM Framework provides a new analytical tool for investigating science practice-based teaching, with a unique lens that considers the rationale behind instructional choices. To build mechanistic explanations for teacher implementation of science practice-based instruction, we think that more work using the CRM Framework as a lens to examine stimulated recall or other forms of teacher interviews should be performed. Because the framework highlights teachers' rationale, it may have limited use for analysis of classroom dialog alone, as assuming teachers' goals based on their actions alone can lead to misinterpretation. Additionally, we see this type of work as related to instructor "intentions" and our previous investigation of instructor intentions in science practice-based instruction (Cooper et al., 2022). In short, there are many aspects of teacher reasoning that should be explored as we work toward understanding the different ways that diverse populations of teachers, in both K-12 and undergraduate settings, navigate this type of pedagogy.

We believe that the CRM Framework is a tool that can be useful for developing PD for teachers. We have productively used the CRM Framework in our own PD design to support TAs in implementing science practice-based instruction in the AIM-Bio curriculum. One of the main ways we have used the CRM Framework is to combat the ways that TAs attempt to apply traditional ways of teaching they experienced as students themselves, a challenge that can lead to conflicts with the goals of practice-based instruction. This choice was motivated by previous research documenting similar challenges among teachers at multiple educational levels (Crawford, 2007; Ford & Wargo, 2007; Ginath & Southerland, 2019; Rudolph, 2008; Sandi-Urena et al., 2011; Wheeler et al., 2017; Windschitl & Thompson, 2006; Windschitl et al., 2008). We have used the CRM Framework in two ways to address this challenge. First, we frame teaching in our context as "research mentoring." This consistent theme is carried throughout our PD program, contextualizing our presentation of specific CRM goals or tools. Two CRM goals are presented to TAs in each PD unit, along with different activities and opportunities for reflection around the specific goals. For example, TAs read an excerpt of teacher-student dialog (from the context they are preparing to teach) and identify moments in which teacher actions support specific CRM goals. Second, CRM tools are an important resource as TAs often begin teaching with no pedagogical training (Mutambuki & Schwartz, 2018; Schussler et al., 2015). We coach the TAs in the use of CRM tools as specific strategies that may be useful in their own teaching.

We believe that the ways we have used the CRM Framework to support teacher PD could be adapted for use in K-12 education. It is yet unknown how the differences between these contexts might impact the features of classroom research mentoring. Although our work demonstrates the applicability of the framework in the context of an undergraduate laboratory course, it is important to remember that the model-based inquiry curriculum in this study was explicitly designed drawing from the literature on K-12 science-practice-based curricula (Lehrer & Schauble, 2006b; Stewart et al., 2005; Wigfield & Eccles, 2000; Windschitl et al., 2008). While there are certainly important distinctions between these contexts, many of the instructional challenges are similar. Centrally, the shift from "learning about" scientific ideas to making sense of scientific ideas to build explanations requires fundamental changes to teaching norms, in any context (Reiser et al., 2017; Schwarz et al., 2017). To facilitate this shift, previous reports of PD for K-12 teachers recommend supporting teacher learning through opportunities for sensemaking about classroom cases (Reiser et al., 2017). As we describe in the previous paragraph, we have had success with a similar approach in which TAs unpack classroom cases, using goals from the CRM framework as a way to relate teaching approaches to research mentoring.

Previous research has identified teaching identity, teacher beliefs, and teaching values as key targets of PD to promote the implementation of reformed science curricula (Anderson, 1996; Gess-Newsome, 2015; Johnson, 2006; Luehmann, 2007). The CRM Framework and results of our study relate to this research through our choice to pay attention to not only to what the teacher does but also to their goals for their teaching choices and their overarching motivation for their teaching approach. Importantly, our work provides a potential way for teachers to reimagine their role in the classroom as encompassing aspects of research mentoring, with the associated values, beliefs, and aspects of identity that accompany participation in science practice. Although this view of the CRM framework suggests a radical shift, there are ways in which the framework should be accessible to practicing K-12 teachers. For example, the CRM tools are worded in ways that overlap with teacher supports that many K-12 teachers are familiar with, for example, scaffolding or articulation. PD activities for this population could focus on building on their current knowledge about these pedagogical supports in ways that help them consider ways to transform these strategies to support their students in science practices.

4.4 | Limitations and future directions

This study provides novel insight into translating research mentoring into the classroom, but there are limitations in the generalizability of our results. We carried out a case study approach to facilitate a careful examination of how a research mentoring framework could be used in the classroom. This approach has limitations as it does not allow for generalizations to be made. Additionally, there are limitations in our choice of teachers to be included in the study. We purposefully chose teachers who were experienced scientists, which only represented a single teaching population. These teachers were also chosen as they had different levels of teaching expertise and could illustrate some of the potential diversity of the CRM Framework. Though we make some suggestions for how the CRM Framework could apply to teachers from different backgrounds, we cannot extrapolate how this would apply to others based on this single study.

Our study proposes a way to reframe inquiry teaching and points to a need for further investigations connecting research mentoring and classroom teaching. Additionally, studies are needed to investigate how a CRM Framework applies to describe different teachers, different inquiry classrooms, and different disciplines. In ongoing work, we are investigating how diverse student TAs approach inquiry instruction, considering the CRM Framework as an explicit framework for reframing the role of the teacher in our context. Future work could consider the CRM as a PD tool for novice science mentors such as graduate students or new faculty as they navigate productive ways to support science in the laboratory.

ACKNOWLEDGMENTS

This work was funded by a grant from the National Science Foundation – Improving Undergraduate Science Education (DUE-2020788). In addition, this research was made possible in part through support from CUES, the Center for University Education Scholarship at the University of Arizona. Any views, findings, or recommendations hereby expressed are those of the author(s) only.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author, MB. The data are not publicly available due to restrictions to protect the privacy of human research subjects.

REFERENCES

Aikens, M. L., Sadselia, S., Watkins, K., Evans, M., Eby, L. T., & Dolan, E. L. (2016). A social capital perspective on the mentoring of undergraduate life science researchers: An empirical study of undergraduate–postgraduate–faculty triads. *CBE—Life Sciences Education*, *15*(2), ar16.

Allen, T. (2003). Relationship effectiveness for mentors: Factors associated with learning and quality. *Journal of Management*, *29*(4), 469–486.

American Association for the Advancement of Science. (2011). *Vision and change in undergraduate biology education: A call to action*.

Anderson, R. D. (1996). *Study of curriculum reform. [Volume I: Findings and conclusions.] Studies of education reform*. US Government Printing Office, Superintendent of Documents.

Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., Hanauer, D. I., Lawrie, G., McLinn, C. M., Pelaez, N., Rowland, S., Towns, M., Trautmann, N. M., Varma-Nelson, P., Weston, T. J., & Dolan, E. L. (2014). Assessment of course-based undergraduate research experiences: A meeting report. *CBE—Life Sciences Education*, *13*(1), 29–40.

Ayar, M. C., & Yalvac, B. (2016). Lessons learned: Authenticity, interdisciplinarity, and mentoring for STEM learning environments. *International Journal of Education in Mathematics, Science and Technology*, *4*(1), 30–43.

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112.

Biggers, M., & Forbes, C. T. (2012). Balancing teacher and student roles in elementary classrooms: Preservice elementary teachers' learning about the inquiry continuum. *International Journal of Science Education*, *34*(14), 2205–2229.

Bismack, A. S., Davis, E. A., & Palincsar, A. S. (2022). Science practice-readiness: Novice elementary teachers' developing knowledge of science practices. *Science Education*, *106*(2), 364–384.

Bolger, M. S., Osness, J. B., Gouvea, J. S., & Cooper, A. C. (2021). Supporting scientific practice through model-based inquiry: A students'-eye view of grappling with data, uncertainty, and community in a laboratory experience. *CBE—Life Sciences Education*, *20*(4), ar59.

Brew, A. (2010). Imperatives and challenges in integrating teaching and research. *Higher Education Research & Development*, *29*(2), 139–150.

Brewe, E. (2008). Modeling theory applied: Modeling instruction in introductory physics. *American Journal of Physics*, *76*(12), 1155–1160.

Brondyk, S., & Searby, L. (2013). Best practices in mentoring: Complexities and possibilities. *International Journal of Mentoring and Coaching in Education*, *2*(3), 189–203.

Brown, R. T., Daly, B. P., & Leong, F. T. L. (2009). Mentoring in research: A developmental approach. *Professional Psychology: Research and Practice*, *40*(3), 306–313.

Buchanan, A. J., & Fisher, G. R. (2022). Current status and implementation of science practices in course-based undergraduate research experiences (CUREs): A systematic literature review. *CBE—Life Sciences Education*, *21*(4), ar83.

Burden, P. R. (2000). *Powerful classroom management strategies: Motivating students to learn*. Corwin Press.

Calderhead, J. (1981). Stimulated recall: A method for research on teaching. *British Journal of Educational Psychology*, *51*(2), 211–217.
Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218.
Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching*, *44*(6), 815–843.
Chinn, C. A., Buckland, L. A., & Samarapungavan, A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational psychologist*, *46*(3), 141–167.
Collins, A. (2005). Chapter 4: Cognitive apprenticeship, In *The Cambridge handbook of the learning sciences*. University Press.
Cooper, A. C., Southard, K. M., Osness, J. B., & Bolger, M. S. (2022). The instructor's role in a model-based inquiry laboratory: Characterizing instructor supports and intentions in teaching authentic scientific practices. *CBE—Life Sciences Education*, *21*(1), ar9.
Corwin, L. A., Ramsey, M. E., Vance, E. A., Woolner, E., Maiden, S., Gustafson, N., & Harsh, J. A. (2022). Students' emotions, perceived coping, and outcomes in response to research-based challenges and failures in two sequential CUREs. *CBE—Life Sciences Education*, *21*(2), ar23.
Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, *44*(4), 613–642.
Davidson, S. G., & Hughes, R. (2018). Communities of practice as a framework to explain teachers' experiences within the community of science. *Journal of Research in Science Teaching*, *55*(9), 1287–1312.
Dolan, E. L., & Johnson, D. (2010). The undergraduate–postgraduate–faculty triad: Unique functions and tensions associated with undergraduate research experiences at research universities. *CBE—Life Sciences Education*, *9*(4), 543–553.
Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and instruction*, *20*(4), 399–483.
Estrada, M., Woodcock, A., Hernandez, P. R., & Schultz, P. W. (2011). Toward a model of social influence that explains minority student integration into the scientific community. *Journal of Educational Psychology*, *103*(1), 206–222.
Feldman, A., Divoll, K., & Rogan-Klyve, A. (2008). Research education of new scientists: Implications for science teacher education. *Journal of Research in Science Teaching*, *46*(4), 442–459.
Feldman, A., Divoll, K. A., & Rogan-Klyve, A. (2013). Becoming researchers: The participation of undergraduate and graduate students in scientific research groups. *Science Education*, *97*, 218–243.
Feldon, D. F., Peugh, J., Timmerman, B. E., Maher, M. A., Hurst, M., Strickland, D., Gilmore, J. A., & Stiegelmeyer, C. (2011). Graduate students' teaching experiences improve their methodological research skills. *Science*, *333*(6045), 1037–1039.
Ferrare, J. J. (2019). A multi-institutional analysis of instructional beliefs and practices in gateway courses to the sciences. *CBE—Life Sciences Education*, *18*(2), ar26.
Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404–423.
Ford, M. (2008). 'Grasp of practice' as a reasoning resource for inquiry and nature of science understanding. *Science & Education*, *17*(2), 147–177.
Ford, M. J. (2005). The game, the pieces, and the players: Generative resources from two instructional portrayals of experimentation. *Journal of the Learning Sciences*, *14*(4), 449–487.
Ford, M. J. (2015). Educational implications of choosing "practice" to describe science in the next generation science standards. *Science Education*, *99*(6), 1041–1048.
Ford, M. J., & Forman, E. A. (2006). Chapter 1: Redefining disciplinary learning in classroom contexts. *Review of Research in Education*, *30*(1), 1–32.
Ford, M. J., & Wargo, B. M. (2007). Routines, roles, and responsibilities for aligning scientific and classroom practices. *Science Education*, *91*(1), 133–157.
Forman, E. A. (2018). The practice turn in learning theory and science education. In D. Kritt (Ed.), *Constructivist education in an age of accountability*. Palgrave Macmillan. https://doi.org/10.1007/978-3-319-66050-9_5
Gafney, L. (2005). The role of the research mentor/teacher. *Journal of College Science Teaching*, *34*(4), 52.
Gellert, U. (2000). Mathematics instruction in safe space: Prospective elementary teachers' views of mathematics education. *Journal of Mathematics Teacher Education*, *3*(3), 251–270.
Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK summit. In A. Berry, P. Friedrichsen & J. Loughran (Eds.), *Reexamining pedagogical content knowledge in science education* (pp. 28–42). Routledge.
Ginath, A. S., & Southerland, S. A. (2019). Applying the ambitious science teaching framework in undergraduate biology: Responsive talk moves that support explanatory rigor. *Science Teacher Education*, *103*, 92–122.
Goertzen, R. M., Scherr, R. E., & Elby, A. (2010). Tutorial teaching assistants in the classroom: Similar teaching behaviors are supported by varied beliefs about teaching and learning. *Physical Review Special Topics - Physics Education Research*, *6*(1), 010105.

Goodwin, E. C., Anokhin, V., Gray, M. J., Zajic, D. E., Podrabsky, J. E., & Shortlidge, E. E. (2021). Is this science? Students' experiences of failure make a research-based course feel authentic. *CBE—Life Sciences Education*, *20*(1), ar10.

Gouvea, J., & Passmore, C. (2017). 'Models of' versus 'Models for'. *Science & Education*, *26*(1), 49–63.

Gouvea, J., Wagh, A., Hayes, R., & Simon, M. (2022). Hybrid labs: How students use computer models to motivate and make meaning from experiments. In N. J. Pelaez, S. M. Gardner, & T. R. Anderson (Eds.), *Trends in Teaching Experimentation in the Life Sciences* (pp. 395–413). Springer, Cham.

Graham, M. J., Frederick, J., Byars-Winston, A., Hunter, A. B., & Handelsman, J. (2013). Increasing persistence of college students in STEM. *Science*, *341*(6153), 1455–1456.

Guy-Gaytán, C., Gouvea, J. S., Griesemer, C., & Passmore, C. (2019). Tensions between learning models and engaging in modeling. *Science & Education*, *28*, 843–864.

Harwood, W. S., Hansen, J., & Lotter, C. (2006). Measuring teacher beliefs about inquiry: The development of a blended qualitative/quantitative instrument. *Journal of Science Education and Technology*, *15*(1), 69–79.

Henderson, J. B., MacPherson, A., Osborne, J., & Wild, A. (2015). Beyond construction: Five arguments for the role and value of critique in learning science. *International Journal of Science Education*, *37*(10), 1668–1697.

Hester, S. D., Nadler, M., Katcher, J., Elfring, L. K., Dykstra, E., Rezende, L. F., & Bolger, M. S. (2018). Authentic Inquiry through Modeling in Biology (AIM-Bio): An introductory laboratory curriculum that increases undergraduates' scientific agency and skills. *CBE Life Sciences Education*, *17*(4), 63.

Jaber, L. Z., Dini, V., & Hammer, D. (2022). "Well that's how the kids feel!"—Epistemic empathy as a driver of responsive teaching. *Journal of Research in Science Teaching*, *59*(2), 223–251.

Jaber, L. Z., & Hammer, D. (2016). Learning to feel like a scientist. *Science Education*, *100*(2), 189–220.

Johnson, C. C. (2006). Effective professional development and change in practice: Barriers science teachers encounter and implications for reform. *School Science and Mathematics*, *106*(3), 150–161.

Justi, R., & Van Driel, J. (2005). The development of science teachers' knowledge on models and modelling: Promoting, characterizing, and understanding the process. *International Journal of Science Education*, *27*(5), 549–573.

Kapon, S. (2016). Doing research in school: Physics inquiry in the zone of proximal development. *Journal of Research in Science Teaching*, *53*(8), 1172–1197.

Klahr, D., Fay, A. L., & Dunbar, K. (1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology*, *25*(1), 111–146.

Ko, M. L. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education*, *103*(4), 979–1010.

Kram, K. E. (1983). Phases of the mentor relationship. *Academy of Management Journal*, *26*(4), 608–625.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lehrer, R., & Schauble, L. (2013). Modeling in mathematics and science, In *Advances in instructional psychology* (pp. 101–159). Routledge.

Lehrer, R., & Schauble, L. (2006a). Scientific thinking and science literacy. In K. A. Renninger, I. E. Sigel, W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology: Child psychology in practice* (pp. 153–196). John Wiley & Sons Inc.

Lehrer, R., & Schauble, L. (2006b). Cultivating model-based reasoning in science education. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 371–387). Cambridge University Press.

Limeri, L. B., Asif, M. Z., Bridges, B. H., Esparza, D., Tuma, T. T., Sanders, D., Morrison, A. J., Rao, P., Harsh, J. A., Maltese, A. V., & Dolan, E. L. (2019a). "Where's my mentor?!" Characterizing negative mentoring experiences in undergraduate life science research. *CBE—Life Sciences Education*, *18*(4), ar61.

Limeri, L. B., Asif, M. Z., & Dolan, E. L. (2019b). Volunteered or voluntold? The motivations and perceived outcomes of graduate and postdoctoral mentors of undergraduate researchers. *CBE—Life Sciences Education*, *18*(2), ar13.

Linnenbrink-Garcia, L., Patall, E. A., & Pekrun, R. (2016). Adaptive motivation and emotion in education: Research and principles for instructional design. *Policy Insights from the Behavioral and Brain Sciences*, *3*(2), 228–236.

Luehmann, A. L. (2007). Identity development as a lens to science teacher preparation. *Science Education*, *91*(5), 822–839.

Lunsford, L. G., Crisp, G., Dolan, E. L., & Wuetherick, B. (2017). Mentoring in higher education. *The SAGE handbook of mentoring*, *20*, 316–334.

Malachowski, M., Osborn, J. M., Karukstis, K. K., Kinzie, J., & Ambos, E. L. (2020). Chapter 4: Scaffolding research into undergraduate STEM curricula and cultures: An emerging model for systemic change, *Transforming Institutions: Accelerating Systemic Change in Higher Education*. Pressbooks.

Männikkö, I., & Husu, J. (2019). Examining teachers' adaptive expertise through personal practical theories. *Teaching and Teacher Education*, *77*, 126–137.

Manz, E., Lehrer, R., & Schauble, L. (2020). Rethinking the classroom science investigation. *Journal of Research in Science Teaching*, *57*(7), 1148–1174.

Manz, E., & Suárez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. *Science Education*, *102*(4), 771–795.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage.
Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching*, *55*(7), 1053–1075.
Mutambuki, J. M., & Schwartz, R. (2018). We don't get any training: The impact of a professional development model on teaching practices of chemistry and biology graduate teaching assistants. *Chemistry Education Research and Practice*, *19*(1), 106–121.
National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
Nersessian, N. J. (2010). *Creating scientific concepts*. MIT Press.
NGSS Lead States. (2013). Next Generation Science Standards: For states, by states *(Vol. 1, The Standards)*. The National Academies Press.
Passmore, C., Gouvea, J. S., & Giere, R. (2014). Models in science and in learning science: Focusing scientific practice on sense-making. In M Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1171–1202). Springer, Dordrecht.
Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modelling classrooms. *International Journal of Science Education*, *34*(10), 1535–1554.
Pfund, C., Byars-Winston, A., Branchaw, J., Hurtado, S., & Eagan, K. (2016). Defining attributes and metrics of effective research mentoring relationships. *AIDS and Behavior*, *20*, 238–248.
Radoff, J., Jaber, L. Z., & Hammer, D. (2019). "It's scary but it's also exciting": Evidence of meta-affective learning in science. *Cognition and Instruction*, *37*(1), 73–92.
Ravitz, J. L., Becker, H. J., & Wong, Y. (2000). *Constructivist-compatible beliefs and practices among US teachers. Teaching, learning, and computing: 1998 National Survey Report #4*. Center for Research on Information Technology and Organizations.
Reid, J. W., & Gardner, G. E. (2020). Navigating tensions of research and teaching: Biology graduate students' perceptions of the research–teaching nexus within ecological contexts. *CBE—Life Sciences Education*, *19*(3), ar25.
Reiser, B. J., Michaels, S., Moon, J., Bell, T., Dyer, E., Edwards, K. D., McGill, T. A. W., Novak, M., & Park, A. (2017). Scaling up three-dimensional science learning through teacher-led study groups across a state. *Journal of Teacher Education*, *68*(3), 280–298.
Rudolph, J. (2008). Commentary on "*Inquiry, activity, and epistemic practice*". In R. Duschl & R. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 118–122). Sense Publishers.
Sandi-Urena, S., Cooper, M. M., & Gatlin, T. A. (2011). Graduate teaching assistants' epistemological and metacognitive development. *Chemistry Education Research and Practice*, *12*(1), 92–100.
Schussler, E. E., Read, Q., Marbach-Ad, G., Miller, K., & Ferzli, M. (2015). Preparing biology graduate teaching assistants for their roles as instructors: An assessment of institutional approaches. *CBE—Life Sciences Education*, *14*(3), ar31.
Schwartz, S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, *88*(4), 610–645.
Schwarz, C. V., Ke, L., Salgado, M., & Manz, E. (2022). Beyond assessing knowledge about models and modeling: Moving toward expansive, meaningful, and equitable modeling practice. *Journal of Research in Science Teaching*, *59*, 1086–1096.
Schwarz, C. V., Passmore, C., & Reiser, B. J. (2017). *Helping students make sense of the world using next generation science and engineering practices*. NSTA Press.
Shanahan, J. O., Ackley-Holbrook, E., Hall, E., Stewart, K., & Walkington, H. (2015). Ten salient practices of undergraduate research mentors: A review of the literature. *Mentoring & Tutoring: Partnership in Learning*, *23*(5), 359–376.
Shkedi, A. (2005). *Multiple case narrative: A qualitative approach to studying multiple populations*. John Benjamins Publishing.
Shore, C. (2005). Toward recognizing high-quality faculty mentoring of undergraduate scholars. *Journal on Excellence in College Teaching*, *16*(2), 111–136.
Starr, C. R., Hunter, L., Dunkin, R., Honig, S., Palomino, R., & Leaper, C. (2020). Engaging in science practices in classrooms predicts increases in undergraduates' STEM motivation, identity, and achievement: A short-term longitudinal study. *Journal of Research in Science Teaching*, *57*(7), 1093–1118.
Stewart, J., Cartier, J. L., & Passmore, C. M. (2005). Developing understanding through model-based inquiry. In M. S. Donovan & J. D. Bransford (Eds.), *How students learn* (pp. 515–565). National Academies Press.
Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education*, *98*(3), 487–516.
Stroupe, D., Caballero, M. D., & White, P. (2018). Fostering students' epistemic agency through the co-configuration of moth research. *Science Education*, *102*(6), 1176–1200.

Stuart, C., & Thurlow, D. (2000). Making it their own: Preservice teachers' experiences, beliefs, and classroom practices. *Journal of Teacher Education*, *51*(2), 113–121.

Tellis, W. (1997). Application of a case study methodology. *The Qualitative Report*, *3*(3), 1–19.

Thiry, H., Laursen, S. L., Hunter, A. B., Thiry, H., Laursen, S. L., & Hunter, A. B. (2011). What experiences help students become scientists? A comparative study of research and other sources of personal and professional gains for STEM undergraduates. *The Journal of Higher Education*, *82*(4), 357–388.

Tien, L. T., Teichert, M. A., & Rickey, D. (2007). Effectiveness of a MORE laboratory module in prompting students to revise their molecular-level ideas about solutions. *Journal of Chemical Education*, *84*(1), 175.

Tuma, T. T., Adams, J. D., Hultquist, B. C., & Dolan, E. L. (2021). The dark side of development: A systems characterization of the negative mentoring experiences of doctoral students. *CBE—Life Sciences Education*, *20*(2), ar16.

Varelas, M., House, R., & Wenzel, S. (2005). Beginning teachers immersed into science: Scientist and science teacher identities. *Science Education*, *89*(3), 492–516.

Varelas, M., Pappas, C. C., Kane, J. M., Arsenault, A., Hankes, J., & Cowan, B. M. (2008). Urban primary-grade children think and talk science: Curricular and instructional practices that nurture participation and argumentation. *Science Education*, *92*(1), 65–95.

Velasco, J. B., Knedeisen, A., Xue, D., Vickrey, T. L., Abebe, M., & Stains, M. (2016). Characterizing instructional practices in the laboratory: The laboratory observation protocol for undergraduate STEM. *Journal of Chemical Education*, *93*, 1191–1203.

Walker, J. P., Sampson, V., Southerland, S., & Enderle, P. J. (2016). Using the laboratory to engage all students in science practices. *Chemistry Education Research and Practice*, *17*(4), 1098–1113.

Watkins, J., & Manz, E. (2022). Characterizing pedagogical decision points in sense-making conversations motivated by scientific uncertainty. *Science Education*, *106*, 1408–1441.

Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems Thinker*, *9*(5), 2–3.

Wheeler, L. B., Maeng, J. L., Chiu, J. L., & Bell, R. L. (2017). Do teaching assistants matter? Investigating relationships between teaching assistants and student outcomes in undergraduate science laboratory classes. *Journal of Research in Science Teaching*, *54*(4), 463–492.

Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of achievement motivation. *Contemporary Educational Psychology*, *25*(1), 68–81.

Windschitl, M., & Thompson, J. (2006). Transcending simple forms of school science investigation: The impact of preservice instruction on teachers' understandings of model-based inquiry. *American Educational Research Journal*, *43*(4), 783–835.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941–967.

Wong, S. L., & Hodson, D. (2009). From the horse's mouth: What scientists say about scientific investigation and scientific knowledge. *Science Education*, *93*(1), 109–130.

Yin, R. K. (2012). Case study methods. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf & K. J. Sher (Eds.), *APA handbook of research methods in psychology, Vol. 2. Research designs: Quantitative, qualitative, neuropsychological, and biological* (pp. 141–155). American Psychological Association. https://doi.org/10.1037/13620-009

Zagallo, P., Meddleton, S., & Bolger, M. S. (2016). Teaching real data interpretation with models (TRIM): Analysis of student dialogue in a large-enrollment cell and developmental biology course. *CBE—Life Sciences Education*, *15*(2), ar17.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Cooper, A. C., & Bolger, M. S. (2023). The Classroom-Research-Mentoring Framework: A lens for understanding science practice-based instruction. *Science Education*, 1–33. https://doi.org/10.1002/sce.21835