What Student Struggles do Instructors see? Teacher Knowledge of Students in Course-Based Undergraduate Research Experiences

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ABSTRACT

Course-based undergraduate research experiences (CUREs) increase student access to research, providing opportunities for more students to engage with science practices and make novel science contributions. However, little is known about how to teach CUREs effectively. Effective CURE instruction relies on an instructor's knowledge of students, which is used to notice and respond to students as they conduct research. This study investigates CURE instructor knowledge of students that resulted from previous noticing when students experience research challenges. We surveyed a national sample of experienced CURE instructors about the challenges they have seen students experience that are distinctive to CUREs. Analysis from our deductive and inductive qualitative analysis of instructors' knowledge of students indicated that they paid attention to student struggles in two main areas: nature of science and research as a practice. Instructor interpretations within these two areas provided nuanced insight into their knowledge of students' knowledge, skills, and emotions across research challenges. Our results provide new insight into CURE instructor knowledge of students that was developed from noticing, which has implications for future research on CURE instruction and instructor professional development.

INTRODUCTION

Participation in undergraduate research can positively impact students' development as scientists (Nagda *et al.*, 1998; Seymour *et al.*, 2004; Hunter *et al.*, 2007; Laursen *et al.*, 2010; Gentile *et al.*, 2017). However, traditional mentored research experiences are limited in number and are typically available to a selected or self-selecting subset of students (Lopatto, 2008; Wei and Woodin, 2011). Course-based undergraduate research experiences (CUREs) can serve a critical role in broadening student access to research (Bangera and Brownell, 2014). CUREs involve all students enrolled in a course in addressing novel research questions or problems of interest to stakeholders outside of the course (Auchincloss *et al.*, 2014). CUREs have been championed for increasing student participation in research, providing opportunities for more students to engage in scientific practices and make novel scientific contributions (Brownell *et al.*, 2012; Auchincloss *et al.*, 2014). Research on CUREs indicates that these experiences can increase student persistence and success in college and STEM fields (Rodenbusch *et al.*, 2016; Hanauer *et al.*, 2017; Indorf *et al.*, 2019). Although we know CUREs can benefit students, we have only just begun to investigate how instructors teach these courses to realize these benefits (Esparza *et al.*, 2020; Goodwin *et al.*, 2021, 2022, 2023).

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CUREs are designed for students to achieve both research and learning goals, which differ from traditional laboratory courses, which are typically designed to support student learning of fundamental concepts or technical skills. The different goals of CUREs necessitate a shift in the instructor's role; CURE instructors must flexibly adapt their pedagogical approaches to meet students' needs as they conduct research (e.g., Gafney, 2005; Hammer *et al.*, 2012; Cooper *et al.*, 2022). This includes supporting students as they engage in scientific practices such as conducting experiments, troubleshooting experiments, or analyzing data (National Research Council, 2012). These goals push instructors to enact a "classroom research mentoring" approach (Cooper and Bolger, 2024) where they balance dual roles as teachers and research mentors (Shortlidge *et al.*, 2016; Goodwin *et al.*, 2021). Ultimately, CURE teaching differs from traditional laboratory course instruction, requiring instructors to change how they teach.

CURE instructors are tasked with providing both research and emotional support (Shortlidge *et al.*, 2016; Gin *et al.*, 2018; Heim and Holt, 2019; Goodwin *et al.*, 2021). Research support includes developing student knowledge and skills for practicing science (National Research Council, 2012). For example, if students encounter experimental failures in their CURE, an instructor might provide research support by scaffolding them through troubleshooting their experimental approach. This could involve modeling how to evaluate experimental versus control results, such that students develop knowledge about controlled experiments. This could also involve supporting students' metacognitive and technical skill development by helping them reflect on how they carried out the experiment to identify potential sources of error (e.g., pipetting problems and miscalibration of equipment). An instructor could provide emotional support to students as they navigate the unpredictability of research. For example, students who encounter experimental failure might feel frustrated or defeated when their experiment does not work. The instructor might provide emotional support by talking with their students about failure being a normal part of science (Gin *et al.*, 2018; Henry *et al.*, 2019; Goodwin *et al.*, 2021). As many CURE students are conducting research for the first time, receiving emotional support through new scientific challenges may be just as important as receiving research support.

Providing suitable support during CURE instruction requires instructors to *notice* their students' thinking and experiences. Classrooms are complex social environments, making it impossible for an instructor to notice everything that occurs (Sherin and Star, 2011; Van Es and Sherin, 2021). As such, instructors selectively decide what aspects of their students' thinking to attend to or disregard based on their knowledge of the discipline, teaching, and students. In the scenario of students encountering experimental failure, an instructor must first notice that their students would benefit from learning knowledge or skills or receiving emotional support before they can decide if or how they will respond. In addition to enabling instructors to respond in the moment to their students, the act of noticing can build an instructor's *knowledge of their students* (Sherin, 2007; Criswell and Krall, 2017). Instructors can then use this knowledge to guide future student-centered instructional decisions and facilitate their future noticing (Wagner *et al.*, 2007).

In this study, we aim to characterize the instructor's knowledge of students that resulted from previous noticing when students experience challenges during CURE instruction. We were interested in studying instructor knowledge around the *challenges* students experience while engaging in research, as these are likely to be moments when instructor noticing and knowledge are especially important for supporting students. To investigate instructor knowledge of students, we conducted an exploratory study that asked CURE instructors to retrospectively recall common challenges they have observed their students face in their CUREs.

Theoretical Framework

We relied on two theoretical perspectives for this research to characterize CURE instructor knowledge of students that resulted from previous noticing: knowledge of students and teacher noticing. Instructor **knowledge of students** includes an instructor's sense of students' previous knowledge, awareness of common difficulties that students experience, and recognition that students might vary in their thinking on a specific topic (e.g., Carlson *et al.*, 2019; Andrews *et al.*, 2022). **Teacher noticing** describes what instructors "see" and how they make sense of what they see in the classroom (e.g., van Es & Sherin, 2002; Sherin *et al.*, 2011).

Instructor knowledge of students and teacher noticing have a *recursive relationship* (Figure 1; Sherin, 2007; Criswell and Krall, 2017). Instructor knowledge of students develops by reflecting on student thinking that instructors notice on multiple occasions (e.g., Schön, 1983; Kolb, 1984). In this case, instructor knowledge of students represents an instructor's personalized knowledge that is built from their own experiences, rather than knowledge that represents a collective understanding (e.g., demonstrated in literature) and shared beyond a single individual (Carlson *et al.*, 2019). However, these observations alone cannot build an instructor's knowledge of students. Even instructors who notice numerous student ideas while teaching will likely forget many of them by the end of class, failing to build knowledge about student ideas. Instructors must reflect on student ideas they noticed to make sense of the student thinking and begin building new knowledge (e.g., Leijen *et al.*, 2014; Waugh *et al.*, 2025). Instructors who notice the same student idea over multiple occasions are more likely to remember the idea after class, reflect on the noticed idea, and ultimately build knowledge of students (i.e., noticing influences knowledge).

Instructors' knowledge of students shapes what and how they notice in their classrooms (i.e., knowledge influences noticing). Although definitions of instructor noticing vary, most include three components: 1) instructor **attention** or what they observe; 2) instructor **interpretation** or how they make sense of what they observe; and 3) instructor **response** or the decision they make in response to what they observed and how they interpreted it (Chan *et al.*, 2021). Instructors draw upon their knowledge of students as they notice, including what they attend to, how they interpret what they notice, and how they respond instructionally (Figure 1; Kersting, 2008; Jacobs *et al.*, 2010; Dick, 2017). Instructors use their knowledge of students to look for specific events in the classroom (e.g., Sherin, 2007; Sherin and Russ, 2014; Dick, 2017), including anticipating student difficulties (i.e., knowledge as

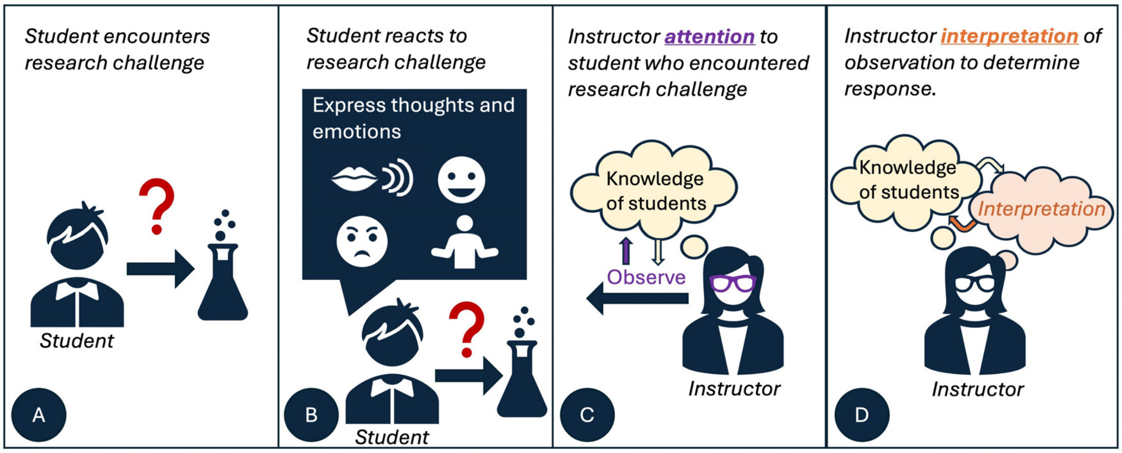

FIGURE 1. Recursive relationship between instructor knowledge of students and noticing in CUREs. (A) CURE students encounter and (B) react to research challenges. (C) Instructors draw from their knowledge of students to selectively observe their students' outward expressions of their thoughts or feelings (i.e., knowledge influences noticing). Instructors also reflect on new observations of their students to build new knowledge of students (i.e., noticing influences knowledge). (D) The instructor interprets what they observed based on their knowledge of students which ultimately influences whether and how they respond instructionally (not depicted).

a lens for observing). Instructors also use their knowledge of students as a tool for making sense of their observations (e.g., Sherin, 2007; Erickson, 2011; Sherin and Russ, 2014; Dick, 2017) and to reason through students' ideas in real time (i.e., knowledge as a lens for interpreting; e.g., Wagner *et al.*, 2007). Finally, instructors draw upon their knowledge of students to decide whether and how to respond instructionally (e.g., Jacobs *et al.*, 2010; Dick, 2017; Waugh *et al.*, 2025). Collectively, instructors vary in their knowledge of students and in their noticing in ways that influence their instructional practices.

In the context of CUREs, instructors are also likely to vary in their knowledge of students in ways that influence what they observe and how they interpret similar observations as their students engage in research. For example, in the scenario of a student encountering experimental failure, an instructor might interpret the student's experimental failure based on their knowledge that students vary in their abilities to physically conduct a protocol or use laboratory equipment. Alternatively, an instructor could hold different knowledge—that students assume their experiments "failed" when they get unanticipated results—and use this knowledge to interpret this observation differently. The different knowledge of students that each instructor relies on to interpret the same observation will ultimately influence their response. An instructor who attributes their student's experimental failure to their student's ability might focus on observing how their student carries out the protocol or uses the equipment to help develop their skills. An instructor who knows students assume their experiment has failed when they get unexpected results might model how to evaluate experimental versus control results to support the development of the students' knowledge about evaluating experimental findings.

Instructor knowledge of students has typically focused on students' topic-specific ideas and thinking. Yet, students' emotions also play an important role in their learning within a research setting (e.g., Jaber and Hammer, 2016a, 2016b). The ways an instructor draws from their knowledge of students to interpret the causes of their students' emotions will also influence how they respond. For example, if an instructor notices their students feeling frustrated after an unsuccessful experiment, they could think that their students were frustrated by shortcomings in their abilities and what this may mean about how "good" a science student they are. Alternatively, an instructor may think students are frustrated because this means they must spend time repeating something they have already done, which is not typically required in demonstration labs. An instructor who thinks their students are frustrated about their ability might focus on bolstering students' confidence by emphasizing other experimental successes or how troubleshooting and problem-solving are a "normal" and valuable part of science. An instructor who interprets students' frustration as a sign that they feel they are investing too much time and effort might emphasize why this investment is worthwhile or how the goals of a CURE differ from those of other laboratory courses. Importantly, instructor noticing depends upon an instructor's ability to make connections between their knowledge of students and the events that are happening in the classroom.

While K-12 education provides examples of instructor knowledge of students' engagement with science practices (e.g., Lee and Luft, 2008; Wei and Liu, 2018), there have yet to be systematic investigations in undergraduate education. Studies in laboratory instruction, specifically with undergraduate or graduate student teaching assistants (TAs), report instructional challenges that provide some preliminary insight into instructor knowledge of students. For example, chemistry graduate TAs reported challenges that students encountered when learning to do acid-based titrations, such as having limited conceptual knowledge and physical skills (Baldwin and Orgill, 2019). In biology, an undergraduate TA who reflected on challenges her students faced when interpreting data reported that her students struggled to account for unexpected results (Cooper *et al.*, 2024). Research is needed at the undergraduate level to better understand instructors' knowledge of student engagement with science practices.

We hypothesize that CURE instructors may hold unique knowledge about their students' engagement with science practices because undergraduate instructors are typically trained as or in training to be professional researchers (e.g., graduate student researchers serving as TAs). As such, they hold distinct professional knowledge about practicing science built from their own experiences doing research (Wong and Hodson, 2009; Cooper and Bolger, 2024). Deeper knowledge of practicing science may provide a "noticing frame" that guides instructors' noticing and eventual development of their knowledge of students. For example, instructors might pay attention to the appropriateness and scope of students' experimental designs to assess the alignment of students' ideas with their research question (Cooper *et al.*, 2022) because of their own knowledge for designing experiments (Cooper and Bolger, 2024). The instructor's knowledge about practicing science can guide what they pay attention to when supporting students' experimental designs, ultimately influencing the knowledge that they build about how students engage in science practices. As such, experienced CURE instructors who hold deep knowledge of practicing science may have distinct knowledge of students developed from their previous noticing experience.

The Current Study

The goal of this exploratory study is to describe CURE instructors' knowledge of students that resulted from previous noticing and could be used in future noticing by addressing the research question: *What knowledge do CURE instructors hold about specific challenges students face in CUREs?*

To answer this question, we surveyed a national sample of experienced CURE instructors about the challenges they have seen students experience that are distinctive to CUREs. We chose to investigate the knowledge of experienced instructors because their previous experiences teaching their CUREs multiple times will have afforded them more opportunities to notice and develop their knowledge of students' CURE-specific challenges (Hale *et al.*, 2016). We implemented a retrospective recall approach that asked instructors to reflect on common student challenges in their own courses. By reflecting on their own students' challenges, we aimed to capture the knowledge of students that was built from their previous observations of and reflections about their students as they taught their CUREs. To describe the knowledge of students that resulted from previous noticing and could be used in future noticing, we conducted deductive and inductive qualitative content analysis on instructors' survey responses and conducted follow-up interviews with a subset of instructors. We then characterized instructor attention and interpretation (i.e., teacher noticing) themes within each instructor's articulated knowledge of students to illuminate the knowledge of students that resulted from their previous noticing.

METHODS

Recruitment and Participants

We recruited a national sample of experienced CURE instructors through email and social media announcements to CURE-related networks and programs in Fall 2023. We asked instructors to complete a short, anonymous survey about the challenges their students faced during CUREs versus other types of courses. Instructors were eligible to participate in the study if they had taught a CURE for at least three terms (i.e., semesters or quarters) and were currently teaching a CURE. From a total of 60 survey responses, 38 instructors met the eligibility criteria and were included in the subsequent analysis of survey responses. Instructors could indicate on their survey if they were willing to participate in a follow-up interview. Of the 38 eligible instructors, 35 expressed interest in being interviewed. We invited nine instructors for interviews because their survey responses reflected a range of student challenges, and we needed more information to understand the instructors' interpretations of student challenges. Six instructors participated in one 30-minute semistructured interview. Instructors who participated in a follow-up interview received a $30 gift card as compensation.

Data Collection

We surveyed instructors using the secure survey platform, Qualtrics. We utilized a retrospective recall approach based on numerous studies showing the utility of this approach for revealing the form of instructor knowledge we sought to understand (e.g., Chan and Hume, 2019). We asked participants to respond to the following open-ended question: "We are interested in challenges students face when completing a CURE versus any other course. What is one way that students have struggled in your CURE specifically?" (refer to Supplemental Materials for full survey). We designed our interview questions to learn more about the student challenge that instructors described in their survey responses. For example, we asked questions like "On your survey you talked about (specific student challenge). Can you tell me a little bit about this challenge?" and "How did you identify this as a challenge?" Refer to Supplemental Materials for the full list of interview questions. All interviews were conducted on Zoom by the first author, ACC. Interviews were audio-recorded, transcribed, and deidentified for analysis.

Data Analysis

We used a combination of deductive and inductive content analysis to develop themes describing CURE instructor knowledge of students built from noticing. We started by analyzing each instructor's survey response. We first used a deductive approach to characterize their attention and interpretation (i.e., teacher noticing) to make inferences about their knowledge of students. We then used an inductive approach to identify emergent subthemes within the instructor attention and interpretation categories. Although the inductive themes emerged from the data, our thinking about the data was guided by our own experiences teaching CUREs and mentoring students in research as well as our understanding of science practices (Ford, 2008; Wong and Hodson, 2009), student-identified CURE challenges (Gin *et al.*, 2018; Corwin *et al.*, 2022), and classroom research mentoring (Cooper and Bolger, 2024). To begin characterizing the instructor attention themes, one researcher (ACC) reviewed the survey responses and wrote analytical memos of attention ideas to develop an initial qualitative codebook. Then two researchers (ACC and ELD) independently applied these initial attention codes to a subset of the data and met to discuss the codes and associated data. During these discussions, we generated and revised the initial attention codes and their definitions to produce the final codebook. All researchers then independently applied the final attention codebook to all 38 survey responses. The researchers engaged in multiple rounds of content analysis and consensus-reaching discussions to resolve all disagreements. Thus, the final coding reflects the researcher's consensus on all survey responses. We then used interview responses to develop a more complete understanding of the final attention codes. One researcher (ACC) identified the code(s) that applied to each interview and pulled these quotes to serve as additional examples.

We found that instructors' knowledge of students not only described student challenges they had observed (i.e., attention) but also provided insights regarding their interpretations of the causes of student challenges (e.g., why students experienced certain CURE situations as challenging). To analyze the interpretation themes, one researcher (ACC) compiled and reviewed all survey and interview responses for each code and developed analytical memos about the ways instructors interpreted their observations. Two researchers (ACC and ELD) then met to review, discuss, and revise ideas about instructor interpretations and finalize our findings, which we present in the results. Both researchers (ACC and ELD) reviewed coding of all instructor interpretations and came to an agreement on the interview quotes presented here.

RESULTS

We characterized instructor knowledge of students that resulted from previous noticing as they taught CUREs. Specifically, we found that experienced CURE instructors held knowledge that indicated they paid **attention** to their students' struggles with what science research is (i.e., the nature of science) and how science is done (i.e., research as a practice; Table 1). Instructors knew their students struggled with four aspects of the nature of science: 1) research is unstructured, 2) research yields unexpected and uncertain results, 3) research involves failure, and 4) research requires collaboration. Instructors also knew their students struggled with three aspects of research as a practice: 1) practicing science, 2) applying concepts to research, and 3) using technical skills.

Instructor **interpretations** further revealed their knowledge of students' knowledge, skills, and emotions. Instructors interpreted some struggles as caused by students' knowledge (or lack thereof), based on students' previous experiences, or how students engaged with research. Instructors interpreted other struggles as caused by students' cognitive and physical skills (or lack thereof) needed to conduct research successfully. Finally, instructors made inferences about students' emotions when they experienced research-related struggles. Next, we describe CURE instructors' knowledge of students reflected in the **attention** themes, alongside their **interpretations** of students' knowledge, skills, and emotions.

Instructor knowledge of students' struggles with the nature of science

Research is unstructured. Research is an unstructured activity, meaning that what, when, and how the tasks of research are completed are not predefined, and the outcomes of the research are unpredictable. Instructors recognized that their students struggled with this lack of structure, including the need to be creative, self-directed, and conscious of time to navigate the unstructured nature of research successfully. Instructors attributed these struggles to students' limited knowledge and skills resulting from their inexperience with research, which could induce negative emotions. For example, one instructor realized that their students struggled with the openness

TABLE 1. Instructor attention to CURE student challenges.

	Attention	Definition Instructors observe their students…
Nature of science	Research is unstructured.	struggle to independently navigate the open-ended nature of conducting research, such as managing their own time or being creative.
	Research yields unexpected and uncertain results.	being unsure about what do when they encounter unexpected results including negative data or “bad” data.
	Research involves failure.	struggle to navigate experimental failure where their samples did not work.
	Research requires collaboration.	encounter challenges effectively collaborating with peers to carry out research tasks.
Research as a practice	Research requires engagement in the practices of science.	struggle to generate research questions, design experiments, interpret data, navigate primary literature or protocols, communicate research, and reason forward to next steps.
	Research requires applying concepts to research.	encounter challenges connecting and applying course content to their research.
	Research requires technical skills.	struggle to navigate the technical aspects of carrying out research, like physically using laboratory tools.
Epistemic affect	Research requires emotional regulation.	express various emotions in response to struggles (e.g., stress, frustration, panic).

of research. Their interpretation of this observation centered around their students' knowledge. They explained that engaging in a CURE was different from their students' previous lab instruction and thus was unfamiliar. The instructor inferred that their students didn't know how to proceed, explaining that *"…[students] struggle with the 'open-endedness' of the CUREs. They are very used to coming to a lab, completing the activities, getting the 'right' answer, and leaving."*

Another instructor realized that their students perceived the workload of a CURE to be higher than their other courses. Their interpretation of this observation centered around their students' skills. They explained that their students were still developing the critical thinking skills that are required to solve research problems with unknown answers:

> *"[The students] think it's a lot more work. So, they think that by using their noggin and thinking critically that it's more work. Why? Because you don't give them the answers, right? So, I don't hand out the answers. I don't say, 'Hey, you know what? Here's what you should get.' It's unknown. So they are gonna struggle with that a little bit, but it'll make them a lot better at the end of the day…"*

Instructors made inferences about the cause of their students' emotions when they engaged with the unstructured nature of research. For example, one instructor recognized that their students felt overwhelmed by the cognitive demand of doing research. They thought that their students felt this way because of the increased complexity of conducting research, which they had not yet experienced:

> *"Sometimes, the amount of skills they learn coupled with the concepts and the complexity of the protocols can be overwhelming, especially in classes that don't have those skills scaffolded throughout the semester and instead are doing very simple labs with much simpler protocols. Going from a level of difficulty of 2 to 8 on a scale of 10."*

Another instructor recognized that it was "scary" and difficult for their students to think creatively and design their own projects in the CURE. They interpreted that their students felt "panicked" when asked to be creative because they are used to passively engaging in classes and may have never been asked to generate their own ideas:

> *"This is the first time that students have been asked to think creatively in science, and it is hard and scary for them. They are used to being lectured at, and they typically panic at the freedom to design their own project."*

Research yields unexpected and uncertain results. Conducting novel experiments in a CURE creates opportunities for students to encounter ambiguous results, and instructors recognized that their students struggled when encountering uncertainty. Uncertainty could be due to their data not clearly supporting or refuting their hypothesis (i.e., ambiguous results) or to their data refuting their hypothesis (i.e., negative results). Uncertainty could also result from limitations in study design and execution, such as the absence of controls or experimental errors that made it impossible to make inferences from the data (i.e., "bad" results). Instructors perceived that these struggles were due to students' limited knowledge about what to do when they encountered uncertain or unexpected results. One instructor explained that their students were used to completing laboratory activities that had predetermined outcomes, and were unsure how to proceed when this was not the case:

> *"The challenge the students face is that 'they don't know if they got the right answer.' They are so used to laboratory exercises that have a correct answer. They are supposed to get a certain slope, or a given melting temperature, and they get immediate feedback about 'whether they are correct.'"*

Another instructor recognized that their students did not understand the importance of negative or unexpected results for drawing conclusions. They explained that their students lacked an understanding of the importance of negative results (knowledge), causing them to ignore it:

> *"There were students that didn't put some data in the [final] poster and I'm like what happened to your antioxidant test? [They were like] 'Oh, it didn't work,' [and] I'm like 'well, but that's still the data that you- you still have to put it [in] there'…even if things don't work that's still the data. The data is the data…I think if they have other things to show they may be like, 'well, why would I even put this in here if I didn't get what I was expecting?'"*

Instructors made inferences about the cause of their students' emotions when they encountered unexpected results. Instructors recognized that their students could feel stressed about the lack of "right answers" in research. They interpreted that their students felt this way due to their limited experience engaging with research and their thinking that the CURE would resemble other laboratory courses:

> *"Overall, the fact that there are no right and wrong answers. For some students that is distressing…I have noticed that some students thrive in CUREs, others get very stressed as there is no clarity as to what they are doing is correct or incorrect (in their mind)."*

Research involves failure. Although experiencing failure is inherent to research, it is a new experience for many students. Instructors recognized that their students struggled to navigate experimental failure and persevere through these setbacks. Again, instructors inferred that this struggle resulted from students' limited knowledge about research. One instructor remarked that their students conflated an experimental failure with a grade failure. They explained that their students' limited experience with failure related to failing grades was because they had only experienced lab exercises working as expected:

> *"I think the students- maybe they're coming from teaching labs where everything is, you know, [a] success. Or even if they don't succeed, they somehow get the data, something happens magically, and the data shows the way it's supposed to be. So, I think they're used to that idea… I think they may be a little bit concerned about if they don't get the results, [that]*

they either [are] not going to succeed in the class or [it says] something about them, not being able to do [science]."

Instructors assumed students felt like they had failed if their experiments failed. They interpreted this observation as an indicator that their students viewed this failure as a reflection of their own individual shortcomings rather than as integral to research or something that could be overcome with troubleshooting:

"Just as humans we want to see things going the way that we expect…when experiments fail to just be like 'oh, it's fine-' I can see that they're kind of like, 'Oh, I- is it me? Did I do something wrong?'"

Another instructor realized that their students' feelings of failure were exacerbated when they compared their progress to the progress of their peers. The instructor thought that their students felt that their experiment failure reflected something about them personally:

"I think when somebody else does it [runs a successful experiment] and they didn't. Theirs didn't work, and the other person's did. I think they feel discouraged and like they did something- they must have failed at it, you know…they start comparing. And then, if a lot of people get bad results. They're like, man. This isn't fun, like science isn't fun."

Research requires collaboration. Although collaboration is not exclusive to CUREs, the challenges associated with collaboration present new and different consequences because they can impact research progress. Instructors attributed some of their students' emotions to how they felt about their classmates' uneven contributions to the research. For example, one instructor thought that their students felt frustrated or bored because of the need to work together despite differences in their abilities to make progress:

"Coming [in] with either very high or very low levels of scientific and laboratory skills. Students who are still mastering some techniques feel frustrated if they see other students finishing up faster, while students that have already mastered the skills needed for certain experiments, tend to get bored, especially in collaborative projects where they need to rely [on] other students for a part of the experiment."

In this example, this instructor inferred that the student who was still mastering research skills was frustrated with their abilities, while the student who had already mastered research skills was bored as they had to wait for their peers to catch up.

Instructor knowledge of students' struggles with research as a practice

Research requires engagement in the practices of science. Instructors recognized that their students struggled to navigate different practices of science, such as reading primary literature, designing research projects, designing experiments, interpreting data, and reasoning about their next experimental steps. For example, one instructor recognized that their students *"struggle with designing their own projects - usually that is a new experience for them,"* inferring that this struggle was due to students' limited experience developing their own investigations and uncertainty about how to do so (knowledge).

Another instructor recognized that their students could follow an experimental protocol but were unable to develop their own procedures. They interpreted this observation as an indicator that their students had the skills to carry out a protocol but did not yet have the skills to develop their own, which was sometimes required for research:

"Students typically do well with very clearly defined, detailed procedures I provide for common laboratory tasks, but struggle when asked to develop a simple procedure for themselves. For instance, students can follow a detailed recipe for preparing a buffer, including all calculations for quantities of reagents, description of necessary labware, and precise sets to follow. When asked to prepare a specific buffer for themselves without these steps, they often find it quite challenging."

Instructors made inferences about the cause of their students' emotions when they engaged with different science practices. For example, instructors realized that their students "freeze" when they do not know how to interpret their data. They interpreted that their students felt this way because they had never been asked to think in these ways before:

"…[doing a CURE requires] a totally different way of thinking. You have to actually look at some data and make your own conclusions. And I find that especially early on, students really struggle with that. They just look at it and they kind of freeze. They don't know what it means."

Research requires applying concepts to research. Conducting research requires connecting information and ideas between the research project and a larger body of knowledge. Instructors recognized that their students struggled to make these connections, especially between their research and relevant science content. Instructors inferred that their students had not yet mastered the content (knowledge) or did not know how to apply the content to their research (skills). One instructor described how, *"This is often [students'] first exposure to research, and [they] often grapple with the cognitive overload of mastering the new academic content while simultaneously being expected to understand and apply it to the research cycle."*

Research requires technical skills. Research requires the use of various tools and techniques that are often new to students (e.g., pipetting or handling samples with care). Instructors recognized that their students struggled to physically use laboratory tools and inferred that their students entered the CURE with different technical skills (as seen in the "research requires collaboration" theme) or still needed to develop knowledge about using different tools. For example, one instructor explained how their students did not yet have the "hidden knowledge" that comes with time and experience conducting different laboratory techniques:

"I think it's a lot of very detailed information… if you were to become a mechanic or something, and you go in and you

work on a car. And you're following this protocol, there's all these hidden tips and tricks that you know just from doing it. They don't know those tricks… We forget that there are a lot of layers of ingrained knowledge with those protocols that they just don't have… there's a lot of hidden knowledge that you learn just from doing it."

DISCUSSION

Here, we provide the first characterization of instructor knowledge of students in CURE instruction. Describing what experienced instructors know, including what has previously drawn their attention and how they interpreted what they had observed based on their knowledge, lays an important foundation for understanding effective CURE teaching. Instructors in our study knew the quality of students' engagement with and understanding of the nature and practices of science. For example, instructors noticed that students ignored or excluded negative data in making interpretations about their results, likely because instructors knew that negative data are important for drawing conclusions and generating new scientific knowledge. Previous research shows that K-12 instructors can observe whether their students engage in different science practices (e.g., whether they pose a research question, collect and analyze data, etc.) but struggle to interpret what they observe or evaluate the scientific quality of students' engagement (Talanquer *et al.*, 2013; Luft *et al.*, 2023; Huang, 2025). We found that CURE instructors provided detailed interpretations that considered the quality of their students' scientific practices. CURE instructors likely hold distinctive knowledge as practicing scientists or scientists in training, which may provide a lens for developing distinctive knowledge of students as they conduct research.

The instructor knowledge of students we describe aligns with and elaborates on what is known about the challenges that CURE students themselves express as they engage with research (Gin *et al.*, 2018; Corwin *et al.*, 2022; Agustian *et al.*, 2025). CURE students report having difficulty carrying out techniques and collecting, analyzing, and interpreting data (Gin *et al.*, 2018). Instructors in our study provided more detailed insights about these challenges, which students may not recognize or be able to articulate. For example, students may be able to recognize when their research yields unexpected results, but they may not know how to identify why this happened or what it could mean. Unexpected results could reflect negative data, which are informative scientifically. Unexpected results could indicate a technical failure during an experiment, which then needs to be repeated. Documenting instructors' perspectives on these challenges is useful for identifying and selecting appropriate instructional responses. For instance, instructors who know students' struggle with negative data could respond productively by providing information about the value of negative data, normalizing the notion that hypotheses are to be tested and refuted rather than proven "right," and modeling how they interpret and draw conclusions from negative data.

Some instructors in our study inferred that students lacked the knowledge and skills needed to navigate this new learning experience. This finding aligns with other studies that illuminate instructors' knowledge about students' limited conceptual knowledge and physical skills (Lee and Luft, 2008; Wei and Liu, 2018; Baldwin and Orgill, 2019). However, these findings also illustrate the important role of instructor framing (e.g., Russ and Luna, 2013). Specifically, our findings show instructor knowledge is often framed from a deficit perspective, as evidenced by their focus on what students are "lacking" (e.g., Schroeder, 2020; Peck, 2021; Gray *et al.*, 2022). Our methodological approach of asking instructors to comment on student struggles may have shifted instructors to identify student deficits rather than assets. Future research could examine instructors' knowledge of the assets that students bring to CUREs, which could be leveraged to help overcome struggles (e.g., Svoboda, 2023). We also encourage instructors to reflect on the *resources* students bring into CUREs that help them navigate the different research challenges identified in Table 1. Importantly, research shows that epistemic engagement is challenging, and student struggles are to be expected. Research on supporting students through productive struggle offers practical recommendations that could be applied to CURE instruction (Posner *et al.*, 1982; Kapur, 2008, 2012; Henry *et al.*, 2019; Chen *et al.*, 2024). For instance, too much support could undermine the productive elements of struggle, while too little support might prompt students to disengage altogether. Thus, CURE instructors could consider the amount of support needed to optimize their students' persistence through setbacks.

CURE instructors in our study held knowledge not only about their students' knowledge and skills, but also about their students' emotions as they conducted research. CUREs may evoke student emotions more than other contexts where instructor knowledge of students has been studied because of the unpredictability of research and students' limited experience with research. Several studies have documented "epistemic affect," or the emotions, feelings, and dispositions experienced while constructing and refining knowledge in a discipline (e.g., Jaber and Hammer, 2016a, 2016b; Davidson *et al.*, 2020). Epistemic affect includes the emotions that scientists (e.g., Keller, 1983; Jaber and Hammer, 2016a, 2016b; Jahren, 2016) and students (e.g., King *et al.*, 2015; Jaber and Hammer, 2016a, 2016b; Agustian *et al.*, 2025) experience when they practice science, rather than how they feel about it. For example, students report experiencing discomfort, or "epistemic anxiety[1]," about not knowing why things went wrong as they conducted experiments (Agustian *et al.*, 2025). Instructors in our study also had knowledge about the anxiousness that students experience in epistemically demanding situations—instances when their students felt stressed and confused about their experiments not working. Importantly, the fact that instructors in our study had knowledge about students' emotions during research engagement reveals that instructors were choosing to pay attention to the ways their students felt and thought it was important. Further research is needed to understand whether and how instructors act on their knowledge of students' emotions in practice (i.e., instructor response) and how this ultimately impacts student learning.

[1]We henceforth refer to "anxiety" as "anxiousness" as the latter better captures the students' *temporary* feelings of unease when conducting research, rather than implying the presence of a diagnosed disorder (Boardman, 2023).

Notably, instructors in our study made inferences about why their students felt emotions during CUREs, and their attributions aligned well with attribution theory, which describes how individuals assign causality to events (Weiner, 1985; Manusov and Spitzberg, 2008). Attributions are posited to share three common properties: whether the cause of the event is perceived to be internal or external to the individual (i.e., locus of causality), whether the cause of the event is perceived as permanent or temporary (i.e., stability), and whether the cause of the event is perceived as controllable by the individual (i.e., controllability). Instructors inferred that students experienced negative emotions because they felt a lack of control when their experiments failed (i.e., lack of controllability). Instructors also inferred that students attributed experimental failures to their own shortcomings (i.e., internal locus of causality). These findings open an avenue for instructors to leverage research on attribution retraining to help their students adaptively frame their experiences with failure in science (Graham and Taylor, 2022). For example, CURE instructors may be able to reduce the anxiousness that students experience in epistemically demanding situations by emphasizing that failure is common in science (external, stable attributions) and not a reflection of them. Furthermore, instructors may be able to apply ideas related to adaptive coping to help students learn to tolerate or minimize stressors (Skinner *et al.*, 2003; Henry *et al.*, 2019). For instance, instructors could teach adaptive coping strategies such as problem solving, information seeking, or emotional regulation. Instructors could also model adaptive coping strategies when students encounter research challenges or provide opportunities for students to reflect on and strategize about navigating challenges they experience.

Our research raises questions about how to prepare and support instructors with comparatively less research experience, such as TAs, in teaching research effectively. In contrast to the experienced CURE instructors in our sample, TAs are in the process of learning to conduct research and may require additional support to develop their own understanding of the nature and practices of science (e.g., Sandi-Urena *et al.*, 2011; Heim and Holt, 2019; Cooper *et al.*, 2024). Professional development could prepare TAs and other instructors who are new to CURE teaching by advancing their understanding of the nature and practices of science (e.g., Cooper *et al.*, 2024), teaching them how to notice students' struggles (e.g., Van Es and Sherin, 2002, 2008), and providing opportunities to reflect on what they observe during teaching (e.g., Schön, 1983; Kolb, 1984) in CURE contexts. For example, scenarios featuring students' CURE-specific struggles (developed from Table 1) could be used to engage instructors in discussing why elements of CURE instruction may be challenging for students. These discussions could prompt instructors to reflect on their own understanding of what research is and how research is done. Instructors could also reflect on the ways their students understand research to develop their knowledge of students and consider how they could guide or support their students in conducting research. Importantly, numerous studies have shown that noticing can be learned through training and practice (Van Es and Sherin, 2002, 2008; Levin *et al.*, 2009; Levin and Richards, 2010). Instructors could observe others teaching CUREs or watch videos of CURE instruction, discussing what they and others noticed, what is important to notice, and whether and how they could respond productively to support students. By developing noticing abilities, instructors should develop knowledge of students that is useful for future noticing and more effective teaching (Sherin, 2007; Sherin and Russ, 2014).

Limitations and Future Directions

This study has several limitations that should be considered in interpreting the results and could be addressed in future research. First, our study does not directly measure CURE instructor noticing in real time, but rather knowledge built from noticing. Future studies could study CURE instructor noticing through different methodological approaches, such as asking instructors to make observations and interpretations in real time when watching video recordings of classes in action. Additionally, future research could investigate how noticing evolves as instructors develop knowledge over time. Second, our study design does not offer insight into the factors that influenced CURE instructor knowledge of students that resulted from previous noticing. For instance, instructor knowledge of students in CURE contexts could be influenced by their own research experience or their experience mentoring others in research. Instructor knowledge of students is also likely to be influenced by previous experience teaching in general or teaching CUREs in particular. Our design choice of collecting anonymous responses limits what we can infer about what may have shaped the knowledge of instructors in our study. To address this, future research should investigate instructor knowledge and noticing in a larger sample of instructors with varied experiences with research, teaching, and mentoring. Finally, our study design does not investigate the impact of CURE instructors' knowledge of students on their teaching behaviors, their students' experiences, or their students' outcomes. Rather, our work characterizes instructors' declarative knowledge that may or may not be used when instructors respond to students in real-time. Future research should investigate how CURE instructors' knowledge of students relates to instructors' teaching decisions as well as to the effectiveness of CUREs for students.

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