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RESEARCH ARTICLE

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Characterizing variations in the figured worlds of teachers and students in science class

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Abstract

This article explores the challenges of enacting reform-oriented curriculum in science classrooms. We use the concept of figured worlds to analyze a case study of an eighth-grade science class where the teacher reported that the students were resistant to changes she was trying to make. By examining stimulated recall interviews with the teacher (including the associated classroom episodes) and post-unit interviews with a subset of the students, we found that the students and the teacher constructed different figured worlds about the science learning in the classroom. These differences centered on the goals that students and teachers had for the class and the roles of the teacher and students in the learning environment. Specifically, we found that there was a lack of alignment around how students and the teacher viewed the purpose of student agency and collaboration and therefore they had different ideas about how they should interact with one another in the classroom. We conclude by discussing the implications of our findings for science education. We believe that the concept of figured worlds allows researchers and teachers to better understand the challenges of implementing reform-oriented practices in science classrooms. This understanding can help teachers and professional development providers to create strategies for bridging the gap between different figured worlds and creating more collaborative and productive learning environments for all students.

KEYWORDS

collaboration, figured worlds, science education reforms, student agency

1 | INTRODUCTION

Ms. Hamilton recently began a 6-week unit with her eighth-grade class investigating the properties of a cup that is supposed to help hot liquids stay hot. Her class just completed a poster of an initial model of how the temperature of a liquid changes in the cup, and her next step is to ask students to write a question on a sticky note that came out of their attempts to explain the phenomenon. This activity should only take a few minutes, but it stretches to 15 min as each step in the process is met with quiet, or not so quiet, resistance from students. The teacher restates the instructions multiple times, with a few more students reluctantly joining the action with each repetition, many of them complaining or responding with sarcasm as they begin. The students are quiet when the teacher wants a response and boisterous when the teacher wants them to work quietly. Everything about the activity appears slow and laborious. Through it all, Ms. Hamilton keeps trying to productively move forward. After finally getting students to post their questions, she realizes students did not follow the directions to post them into specific categories. She ends the class by saying they will need to do that part again tomorrow and implores the class to try to follow the directions so that they do not create more work for themselves. As soon as Ms. Hamilton starts to dismiss the class, the students are up and filing out of the room before she finishes her sentence.

In an interview the following day, Ms. Hamilton, expresses her frustration with how things are going and states that her students blew up at her and said (in her words), "We know all this. I don't want to learn this. I don't want to learn this kind of science. We hate this class. [...] We don't want to do this. You need to start doing more interesting labs because we don't want to participate" (Stimulated Recall [SR] 1-L1). When she asked why the students thought they were having such a hard time moving forward as a class, they responded (in Ms. Hamilton's words): "We don't want to talk because you asked us questions that we can't answer, so we feel dumb" (SR1-L1).

This brief vignette is an example of a common but under-researched challenge in the reform of science education. Ms. Hamilton tries to use the curriculum as intended, asking students to generate questions to guide next steps and ultimately help them make sense of science ideas. Asking questions about a phenomenon in this manner is a critical first step in sensemaking

(Reiser et al., 2021). In many classrooms, these kinds of practices lead to meaningful scientific activity where students act as epistemic agents who pose questions and develop and revise scientific knowledge together (Alzen et al., 2023; Lowell et al., 2022; Manz & Suárez, 2018). However, there are instances when, despite a teacher's consistent attempts to use "best practices" for students' sensemaking, there is a tacit disagreement about the goals that students and teachers hold and the roles they seem to be playing in the classroom. In this article, we explore a case in which things do not go smoothly in the enactment of a sensemaking unit. We argue that this can arise, at least in part, due to the emergence of distinct, but partially overlapping *figured worlds* (Holland et al., 1998) inhabited by students and the teacher.

Science education reforms call for ambitious teaching that supports students in developing science knowledge, engaging in scientific practices, and applying ideas to investigate questions about the world (Braaten & Sheth, 2017; Manz et al., 2020; Miller et al., 2018; National Research Council, 2012). These characteristics remain quite different from those in most science classrooms. Results from the 2018 National Survey of Science and Mathematics Education suggest that students engaged in some science practices (such as evaluating scientific models and engaging in argumentation) only an average of once or twice a month at most (Banilower et al., 2018).

Much work has been done to help teachers make these pedagogical shifts and to see themselves taking up new roles in the classroom. Increasingly, curricular materials and professional learning opportunities are developed to support teachers in changing the ways they see themselves in the classroom, understanding the goals of engaging students in the scientific practices, and enacting classroom strategies for these reforms (Berland et al., 2020; Kawasaki & Sandoval, 2020; Ko & Krist, 2019; McNeill et al., 2022; Schwarz et al., 2017). However, students must also make corresponding shifts in their expectations and accept the rationale for why the changes make sense. One element of this shift entails students moving from expecting teachers to take on a role as the authority in disseminating knowledge to expecting themselves to take agency in knowledge building (Ford & Forman, 2006; Munson, 2021).

As teachers transition their instructional practices and students encounter classrooms that may seem unfamiliar, the teacher and students may have different ideas about what to expect from themselves and others, as well as the significance of particular classroom activities, discourses, and artifacts. In prior work in mathematics, Munson (2021) uses classroom discourse to identify instances of "student push back" on changes teachers attempt to make in the classroom (i.e., when students indicate they remain confused even after being recognized for productive contributions). We build on Munson's work by using teacher and student reflections to identify points of tension that may arise as teachers change how their science classrooms operate. Specifically, we seek to investigate two questions: First, how do students and teachers interpret the goals and individual roles for a practice-focused science classroom? Second, where do these interpretations of goals and roles come into tension with one another? Implications from this study provide insight into how educators may work to confront and negotiate these differences as well as leverage similarities to better support students in transitioning their expectations and experiences in science class.

2 | CONCEPTUAL FRAMEWORK: SHIFTS IN FIGURED WORLDS

We use the concept of figured worlds to investigate classroom members' expectations in the classroom community when teachers enact reform-oriented practices. A figured world is defined as a "socially and culturally constructed realm of interpretation in which *particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others*" (Holland et al., 1998, p. 52). In their foundational work on the theory, Holland et al. (1998) argue that figured worlds rely on individuals' abilities to shape and be shaped by jointly developed "as if" realms of activity. These realms grow through collaborative activities, discussions, and actions, and expectations set forth by participants in the "as if" realm in turn influence subsequent action and give significance to individual's experiences.

Individuals within the figured world co-construct the roles and responsibilities of actors as well as the value placed on different acts and outcomes through engagement in cultural and social activity (Boaler & Greeno, 2000; Holland et al., 1998; Munson, 2021). This is an ongoing and reflexive daily process in which students and teachers continually negotiate their responsibilities in reaction to one another's contributions to the classroom community (Herbel-Eisenmann et al., 2015; Holland et al., 1998; Munson, 2021; Wenger, 1998). Within these spaces, individuals hold expectations for how their words and actions will be interpreted based on their understanding of the context, or the figured world. When these expectations are not met, participants can experience confusion (Holland et al., 1998, p. 52).

Holland et al. (1998) use Alcoholics Anonymous (AA) as one example of a figured world. In order for participants to become successful members of AA, they must take up "a particular understanding of the world [and] a new understanding of their selves and their lives and a reinterpretation of their own pasts. They enter, or rather are recruited to, a new figured world, a new frame of understanding" (p. 66). The telling of personal stories about their lived experiences with alcohol during meetings is one way by which AA participants become a part of the figured world:

> As the AA member learns the AA story model, by listening to and telling stories, and comes to place the events and experiences of his own life into the model, he learns to understanding his own life as an AA life, and himself as an AA alcoholic. The personal story is a cultural vehicle for identity formation. (Holland et al., 1998, p. 71)

By listening to and telling these stories, members experience a reinterpretation of self and retelling of their stories as AA stories. This process can allow members to reinterpret previous experiences and become members of the AA community.

Something notable in Holland et al.'s (1998) work is that just because individuals attempt to participate in AA does not mean that they will ultimately become successful members of the figured world. Adopting the figured world of AA requires individuals to take up a far-reaching reinterpretation of themselves, the act of drinking, individuals who drink, and the role of drinking in larger social and personal contexts. At times, potential AA members chose to reject the AA pursuits and goals as well as others' reframing of their stories. One thing that may encourage this rejection is that of competing voices:

> The AA member may hear the voices of other [AA] members, but she also hears the voices of her friends who still drink: 'Oh, come on, have a drink' And it is unlikely that the member will be able to avoid situations in which these voices, which are reminders of earlier selves, promote divergent actions. (Holland et al., 1998, p. 178)

Holland et al. further assert that success in the figured world cannot be assumed. They argue that individuals may not engage enough or sufficiently to form a relevant identity and become a member of the community. It is also possible that lack of membership can occur if individuals do not fully understand or take up mediating tools.

The figured world framework provides a way to consider how individuals develop self-identities or expected roles, participate in a space, and prepare for how they may participate in the future based on their interactions with other characters as well as activities and artifacts within the space (Eisenhart & Allen, 2016; Holland et al., 1998; Urrieta, 2007). It also provides a framework for understanding how would-be members might experience more or less success within a particular figured world as they strive to reauthor themselves within the figured world's context (Holland et al., 1998). However, identity formation does not stop at self-identities. Students and teachers need to both set expectations for themselves in these new roles as well as be recognized by others in those roles in order to fully shift their expectations (Eisenhart & Allen, 2016). As teachers and students fulfill roles, recognize one another in those roles, embody the values and objectives, construct meaning using relevant artifacts, and engage in the activities of a figured world, they develop identities within and take on the perspectives of the figured world (Boaler & Greeno, 2000; Eisenhart & Allen, 2016; Jurow, 2005).

Coming to a deeper understanding of the transitions in the current science reform environment is important because the culture of the traditional classroom is ingrained in many US schools (Eisenhart & Allen, 2016; Munson, 2021; Stroupe, 2014). In many of these classrooms, teachers and textbooks serve as the primary sources of presumably correct science that must be transmitted to students who passively receive this knowledge. In these classrooms, some of the most significant acts for teachers are to provide information, arbitrate correct answers, and facilitate understanding scientific concepts (Berland et al., 2016; Carlone et al., 2014; Stroupe, 2014). Students most often perform by raising their hands to ask questions, offering potential answers to questions, and having their ideas evaluated by the teacher (Lemke, 1990). A valued outcome is for students to learn the "correct" science, as defined by the teacher and/or textbook, at the pace and order determined by the teacher. Students in these classes typically expect their teacher to tell them if they are correct or incorrect and understand their role as to repeat back to the teacher the knowledge given to them. Munson (2021) characterizes such an approach to teaching and learning as a transmission-based figured world in a mathematics context, and we name it similarly here in science.

Also similar to Munson, we contrast the transmission-based figured world with a sensemaking figured world. Specifically, we are interested in how the goals and roles of students and teachers are understood by these actors in the classroom. For example, as students share ideas, question one another, and make connections among their ideas, they may begin to act as epistemic agents to figure out scientific explanations for puzzling phenomena, rather than learning about them from the teacher (Schwarz et al., 2017). We consider students taking up epistemic agency when they "take, or are granted, responsibility for shaping the knowledge and practice" (Stroupe, 2014, p. 488). Students who have epistemic agency share, test, and revise their own ideas about scientific concepts rather than passively receiving science knowledge from their teachers (Alzen et al., 2023; Berland et al., 2016; Damşa et al., 2010; Miller et al., 2018). In sensemaking classrooms, students do increasingly more agentive work, and they do this in collaboration with one another. The collaborative nature of this work is more than simply working in groups. It is a commitment to "collaborative idea production" or a collective enterprise that requires contributions from all members of the community in order to make progress on scientific understanding (Damşa et al., 2010). In order for such progress to be made, teachers must support students in sharing and making sense of contrasting ideas as a group through principled argumentation and consensus reaching (Carrier, 2013; González-Howard & McNeill, 2019). Prior work characterizes sensemaking classrooms as those in which the teacher actualizes opportunities for students to act as epistemic agents in knowledge-building work and emphasizes that developing science ideas is a collective enterprise in which the class works together. Conversely, in other classrooms, teachers may invite students to act as epistemic agents and pursue collective knowledge building, but the teacher's actions may not successfully support students in taking up those roles (Alzen et al., 2023).

Prior science education research using figured worlds recognizes that while students come into a science classroom, and thus its figured world, they do not fully leave the figured world of their previous experiences with school and science classrooms more generally, often transmission-based figured worlds (Price & McNeill, 2013). These potentially differing figured worlds can create contention for members of the classroom community as participants' expectations for how their contributions will be received are not met and actors in the space do not interact with one another in anticipated ways (Holland et al., 1998; Price & McNeill, 2013; Richmond & Wray, 2023). Price and McNeill (2013) suggest that the ways individuals are given the authority to author themselves within a figured world may or may not afford them opportunities to draw upon their varied past experiences to bridge their prior experiences with science in the current context. Further, the ways that individuals draw on their own histories to author themselves within a space influences their perceptions of current contexts. Richmond and Wray (2023) also argue that joining a figured world occurs, in part, through the actions in which a participant chooses to engage and how that engagement is positioned within the space. When individuals enter into a new figured world, they must work to understand the figured world's culture; thus, simply entering into the space does not mean the participant will immediately feel they are a part of it (Richmond & Wray, 2023). This success (or failure) can be due to a variety of factors, including the participant's understanding and take up of the tools, artifacts, and other mediating elements within the figured world (Holland et al., 1998; Richmond & Wray, 2023).

We use a figured worlds approach to examine a classroom enactment because the changes the teacher in our study introduces into her classroom can be thought of as transitioning her students from a transmission-based figured world of learning science to a sensemaking figured world of learning science. The teacher, through prior experiences with Next Generation Science Standards (NGSS)-aligned curriculum, our research team, and other educators adopting reform-oriented science practices, entered a sensemaking figured world of science and then made moves to construct such a figured world in her classroom. Similar to the AA example, the students in the class experience variable success in becoming members of this figured world based on the extent to which they use the mediating tools and reauthor themselves (Holland et al., 1998). We argue that as students struggle to become members of the sensemaking figured world of science, they may ultimately gravitate more toward appropriating the more familiar mediating tools, practices, and identities of a transmission-based figured world to learning science. While application of figured worlds theory often focuses on the co-construction of a single figured world in a given space, this theory has also been used in prior literature to understand where and how differing figured worlds can be at work in a given space (Munson, 2021; Price & McNeill, 2013). By taking a figured worlds approach to studying these transitions, we can focus our investigation on the ways that a teacher and students co-construct their goals for their work together and the roles and responsibilities within the classroom, two key elements that define figured worlds. This enables us to analyze where there is overlap or mismatch between community members' expectations, and identify ways that tensions are addressed in the transition.

The shift from a transmission-based figured world to a sensemaking figured world of learning science is not unidimensional or binary. There are many aspects of the classroom culture that make up a figured world. The choice of classroom activities and the activity structures used to facilitate those activities, the creation and use of classroom artifacts, the roles assigned to and taken up by individuals, the distribution of authority in knowledge-building work, and classroom goals, are all elements that a teacher may or may not be attending to and be more or less successful with. They are also all elements that can be studied to gain a better understanding of the figured world. In this study, we focus on a case of apparently conflicting expectations to examine how a middle-school teacher and her students identify the *roles* of members of the classroom community as well as the overall *goals* for class generally. Although the focus on only these elements yields an incomplete understanding of the figured world, we argue that considering the tensions that arise in these specific elements of figured worlds can help teachers better understand classroom interactions, manage classroom space, and identify where tensions may create roadblocks for student learning (Braaten & Sheth, 2017; Chaffee & Gupta, 2018). Results from this study have implications for teacher practice, professional learning opportunities, and curricular materials designed to support teachers transitioning their classrooms to reform-oriented practices.

3 | DATA AND METHODS

Data for this study are a subset drawn from a larger study of teacher learning in science instruction. All teachers worked with science curriculum materials designed to support sensemaking-based classrooms and participated in a week-long summer professional development institute. They also participated in virtual study groups that provided ongoing support during implementation. During the process of collecting data for the larger project, varying classroom expectations emerged as a challenge faced by several teachers and particularly for the focal teacher in this article, so we launched a deeper investigation to better understand the potential impacts of these varying classroom expectations. Although we did not initially enter data collection with a figured worlds framework in mind, the emerging evidence of potential mismatch in teacher and student expectations for class suggested it would be a fitting framework for our analysis.

3.1 | Teacher and student participants

Our focal teacher, whom we call Ms. Hamilton, teaches in a large urban district in the Midwest and participated in our professional development during summer 2019. At the time, she had 16 years of teaching experience and taught eighth grade. Prior to participating in our professional development experience, Ms. Hamilton had completed about 120 hours in other professional development and graduate-level coursework that included support in teaching the NGSS (NGSS Lead States, 2013). Additionally, she had taught stand-alone or sample NGSS-designed lessons and one NGSS-designed unit. She had also experimented with adapting lessons from her previous curriculum to better reflect the NGSS. However, taking part in our study was the first time she had access to complete NGSS-designed curriculum materials and professional development support during enactment of that curriculum.

We conducted a pre-enactment interview and survey with all teachers in the study prior to completion of our summer professional development but before enactment of the curriculum, as well as a post-enactment interview several months after the close of the unit. In these surveys and interviews, teachers answered questions about their perceptions of science teaching strategies and their own teaching approaches and goals. During the 2 months that Ms. Hamilton enacted the focal unit, we video recorded a predetermined selection of lessons on five occasions, occurring approximately every 2 weeks during the unit, in which the curriculum suggests whole group discussion was likely to take place. We chose to observe these lessons because we expected a higher likelihood of observing increased interactions among classroom community members. As a result, we hypothesized there would be greater potential to observe ways in which the teacher may afford students opportunities to act as epistemic agents (or not) and to observe how the classroom community may choose to (or choose not to) engage in collective knowledge-building work. After each recorded lesson, we conducted stimulated recall interviews based on excerpts from the classroom video.

We selected excerpts for stimulated recall interviews from instances in class of whole group discussions so that student talk would be observable. For each class observation, we chose two clips totaling fewer than 10 min. We selected clips we considered productive prompts for teachers in which student conversation involved multiple students engaged in sustained interaction with one another and/or the teacher, or when something surprising happened (e.g., students push the conversation to be about something other than what the teacher seems to have intended).

Stimulated recall interviews occurred in person between Ms. Hamilton and the same researcher an average of 13 days (range from 3 to 28 days) following the video recording. For each interview, the researcher asked Ms. Hamilton for any general reflections about the lesson. Then, the researcher showed a preselected clip, asked Ms. Hamilton if she remembered that moment, and then asked her to discuss memories from that moment. The researcher then asked about Ms. Hamilton's reflection or the specific actions or talk she contributed to class during the clip. For example, "Can you talk a little bit about why you were […]?" or "Were you surprised when […]?" (SR1-L1). When Ms. Hamilton made claims about something she said to students during the interviews, we turned to lesson transcripts to substantiate those claims and used that data to illustrate in the results. Thus, data from the stimulated recall interviews come from two sources: classroom video clip transcripts (referred to as L*x* transcript) and from stimulated recall transcripts (referred to as SR*x*-L*x*). The classroom video that was analyzed for this study came from the clips used in the stimulated recall interviews.

Our data also include six student interviews from the end of the unit where we asked students about their experiences with the science class in general, and about roles, authority, and the kinds of actions they expect to occur. Questions included asking students to describe a typical day in class, who decides what will happen in class, if and what rules exist, what students do if they have a question, and what a new student would need to know about class. In response to student answers, the interviewer would ask follow-up questions such as how […] made the students feel, ask them to say more about […], and ask for a specific example to illustrate a more general comment. We asked questions in these ways because we wanted to understand more about how students perceived their experiences in class without potentially leading them to give what they thought were expected answers. For example, asking students who decides what happens or what a general day in class looks like were designed to provide opportunities for students to comment on who has the agency to determine next steps.

The full focal class included 12 students, of whom 10 consented to be a part of our study. Three of the students self-identified as multiracial, six as Black, and one as White. All 10 students' primary language is English; half are female, and the other half are male. Of those

10 students, 6 volunteered to participate in interviews. Interviewees were also half female, half male. One interviewee is multiethnic, four are Black, and one is White. Data from these interview transcripts appear as SI*x* in the results where each number 1–6 represents data from the interview of a certain student.

3.2 | Curriculum materials context

Ms. Hamilton enacted an OpenSciEd curriculum unit, "How can containers keep stuff from warming up or cooling down?" (which we refer to below as "the cups unit"). This unit is organized around the ideas of how a "fancy" cup keeps liquids colder or hotter than a "regular" cup and the scientific ideas of thermal energy transfer (Mohan, 2019). Unit enactment occurred from September 9 to November 8, which is about 1 week longer than the 37 expected days prescribed in the curriculum (fairly typical pacing as many teachers take longer than is prescribed in storyline units when teaching the unit their first or second time).

3.3 | Approach to analysis

We conducted a single case study within our larger dataset of teachers' enactment of new productive sensemaking units. We first coded the teacher stimulated recall interviews to identify how she described her expectations for herself and students and her goals for class. Specifically, we coded for key elements of figured worlds: goals or valued outcomes and roles or significant acts (Holland et al., 1998; Munson, 2021). We also identified moments from the five sets of classroom clip transcripts used in the stimulated recall interviews that supported the ideas the teacher presented in her reflections. Next, we similarly coded student interview transcripts as we did the teacher data, for key elements of figured worlds: how the students characterized the roles and responsibilities for themselves, their peers, and their teacher as well as what they saw as goals for class. Following, we completed thematic analysis regarding goals for class and expectations for classroom participants. This analysis identified key themes across the teacher and student perspectives from their respective interviews as well as their modes of interaction from the classroom enactment. Within those themes, we then created a summary table of data that identified where the student ideas aligned with and varied from the teachers' ideas. We coded student ideas as different whenever they brought in new ideas we did not see evident in the teacher's own reflections. We wrote multiple memos across our analysis process to capture our developing ideas around mismatch and overlap between the students' and teacher's figured world of science class. From those memos, we extracted high-level themes and looked broadly for areas of tension around goals and roles for teacher and students as a way to understand how differing figured worlds may have influenced how the unit unfolded in this class.

4 | RESULTS

The vignette at the beginning of this article illustrated a difficult classroom moment that may seem familiar to many trying to enact reform-oriented practices. When teachers like Ms. Hamilton implement such practices to try to create classroom environments and set expectations that can seem unfamiliar to many students, this transition can be met with resistance.

Our data show that both Ms. Hamilton and her students are aware of the resistance, but they appear to interpret it in different ways. Early in the unit, Ms. Hamilton reports that her students express the following ideas:

> They're like well "you keep asking us questions and you're not answering our questions." And I'm like "the thing is you guys need to hear from each other, and you guys are doing great things. My questions are for you guys to think about it a little bit deeper or to make you think in a different direction so that you understand it better." And they're like, "no you're just trying to make us look dumb in front of each other." And I'm like "no, that's not the purpose." (SR1-L1)

This excerpt highlights the general tension between the expectations Ms. Hamilton and her students have for class. While Ms. Hamilton talks about wanting her students to navigate sensemaking relatively independently by listening to one another and thinking together about questions and science ideas, her students do not yet recognize how they are to do these things productively. Instead, students express frustration because what they expect from asking and answering questions in the classroom is not occurring and causes them to feel unsure about their classroom contributions.

In this section, we highlight the nature of these tensions and explore potential driving factors behind such classroom tensions since Ms. Hamilton and her students have developed different figured worlds of science. We first discuss tensions around varying goals for the classroom space. Second, we identify tensions resulting from differing expectations for teacher and student roles. Finally, we consider how and the extent to which both the students and Ms. Hamilton address these tensions.

4.1 | Issue 1: Tensions due to varying goals for class

One defining feature of figured worlds is the value participants place on particular goals or outcomes (Holland et al., 1998). Following Munson (2021), we examined participants' views of their valued outcomes from their activities. Broadly, we found differences in the interpretation and value that the students and Ms. Hamilton place on two different goals for class: student agency and student collaboration.

4.1.1 | Student agency

One of Ms. Hamilton's main goals for class is that she and her students develop science knowledge together. Ms. Hamilton emphasizes that she gives students agency in knowledge building and works alongside her students to figure out science ideas—an approach very much aligned with the goal of supporting student sensemaking. Ms. Hamilton came to our research project with these goals. Prior to PD, she reported that she hopes that her students are "able to question something in science and work through to figure out the answer" (Pre-PD Survey). Further, when asked about good discussion in class, she noted "I think it is when students take over to share what they know and build on each other's ideas with the teacher as a mediator to help" (Pre-PD Survey). In a reflection about her general approach to teaching, she states: "I'm not going to sit here and say okay everybody grab their pencil and write their name on the sheet and do this" (SR3-L9). Instead, it is important to Ms. Hamilton that her students see her as someone working together with them in a collective enterprise of figuring something out rather than as the source of correct knowledge:

> We have to work together to figure this out. I'm not going to tell you the answer because that's not how life is. You're going to come to a problem that you're going to have to problem-solve [...] and you can't just turn to somebody and be like 'oh, what should I do next?' It doesn't happen. (SR2-L4)

There are multiple instances during class when Ms. Hamilton asks students to clarify or expand for her own understanding in ways that are consistent with these expressed goals: "I heard somebody wonder [about] a greenhouse. Can somebody clarify?" (L1 transcript), and "We talked about an interesting question, and I'm a little confused. So I want to see if you guys can clarify for me" (L12 transcript). Rather than telling students if she agrees or not, she surfaces student ideas and frames them as something she is trying to understand alongside the students, giving them an agentive voice in making sense of ideas. In another lesson, Ms. Hamilton asks questions like "What do you see happening so far?"; "Anything else you noticed about the results"; "Do we agree or disagree?" (L4 transcript). With these questions, Ms. Hamilton continues to invite students' noticing, wondering, and level of consensus rather than telling them what they should see or notice or agree upon.

Student interview data show some potential evidence that suggests students also place some value in ways in which they have agency in class. However, the students' focus on agency is more around decision making than sensemaking. For example, SI3 appreciates the ways that Ms. Hamilton gives students "control" in their investigations: "I liked when we were able to build our own cup and work on that because that was really hands-on. We got to control what we did. [...] We got to decide if we do this or that." This student also comments that picking the people they worked with was an important choice that students could exercise sometimes. Similarly, SI5 mentions that he valued the voice they had in determining the next unit: "We took a Google form to figure out what we want our next unit to be, chemistry or life science, and I picked chemistry."

These students place some value on having agency in class, but many of the examples of where agency manifests in their reflections are not related to knowledge building or shaping practice. Instead, students value agency in the details of class activities or who they work with. This contrasts with the way Ms. Hamilton describes her goals around student agency. While students do have opportunities to be agentive in knowledge-building work in this classroom, it appears that students do not place the same value on or have the same goals about their agency in knowledge building.

Figure 1 illustrates the overlap we see in these data. Both the students and Ms. Hamilton value and desire some level of student agency, but the type of agency is different. While allowing both kinds of student agency in the classroom is possible, if the students are unaware of Ms. Hamilton's goal for them to act as knowledge builders, frustration can occur when their expectations do not match the teacher's expectations.

4.1.2 | Student collaboration

Another valued goal for class Ms. Hamilton holds is students working together to make sense of science ideas. She works to facilitate this by encouraging students to share thoughts, listen to

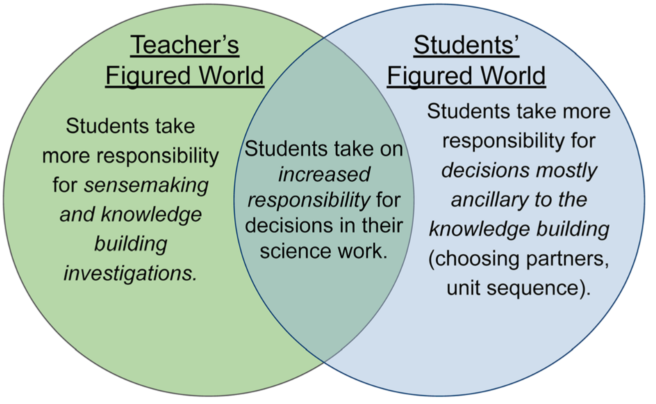

FIGURE 1 Comparing student agency goals for class.

one another, and put their ideas together. For example, Ms. Hamilton reports saying to students: "I overheard really great conversations. [...] We all need to stop and be able to hear their ideas" (SR1-L1). Ms. Hamilton emphasizes students hearing one another "so that they know that I'm acknowledging that I'm hearing good stuff and I want them to be able to share out with other people" (SR1-L1). This element of asking students to share ideas extends beyond initial ideas as well. Ms. Hamilton wants students to connect to others' ideas when they share, and to share when they don't necessarily agree with one another. She says things such as "Okay, does somebody agree or disagree or can add onto that?" (L12 transcript) and "So the [cup] lid helped. Do we agree or disagree? Agree? So we're saying that the lid helped, but how did it help?" (L4 transcript).

In interviews, Ms. Hamilton explains that part of her reason for elevating student ideas is thinking about herself as a student experiencing the class discussion:

> I always try to think about if I was a student sitting here, would I be able to keep up with what's going on? If I'm feeling like I can't keep up with what's going on, I'm like Ok. We need to put a little stop to it and go back. (SR1-L1)

Ms. Hamilton wants students to have the ability to track the conversation and activities, and she encourages students to connect their ideas to one another and identify where they agree or disagree, all elements of collectively working together to build knowledge.

The students also talk about working collaboratively in class, but similar to how they spoke about agency, the students' goals for collaboration are not necessarily completely aligned with Ms. Hamilton's. SI3 indicates that she values being able to select who she works with in class, but she also states: "when we go out in the real world, we aren't able to pick who [we] get to work with all the time, so it's just good to work with somebody else." This student places value on the life skill of learning to work with others, which is different from valuing collaboration for the purpose of considering different perspectives in making sense of ideas. However, SI3 also mentions that working with others provides opportunities to share ideas:

> I really like the way she has her room set up because we can all see each other when we're talking. And when we do small groups it's nice because that way we can work with our peers, and we can share our ideas. (SI3)

While this particular quote does not reveal if SI3 values sharing ideas for making sense of a variety of viewpoints or something else, this statement does show at least some partial alignment with the sensemaking goals set forth by Ms. Hamilton—working with others in order to share ideas with one another is valuable for learning science.

Another aspect of divergence in their views of collaboration is that students place some value on working with others in order to find right answers. SI2 names that his first point of contact when trying to figure something out is other students:

> If I don't understand something, I ask a friend first because that's what they always tell us. So I asked a friend. If they don't know, then I ask another one, and if they don't know, all three of us go up to Ms. Hamilton and ask her. [...] One of the questions where it was very confusing. And we asked for help and she told us, but then we still kinda couldn't get it. So that night we just called each other. We had a whole group facetime chat. (SI2)

SI1 comments on her response when Ms. Hamilton asks her to work with a peer: "Sometimes she'll say dig a little deeper or ask somebody by me, but nobody by me knows how to do it because we're all learning the same things. So I can't really ask somebody." These comments reveal that students see the purpose of working with others as important for sharing information and not necessarily building the answer together by wrestling with incomplete ideas or making sense of competing ideas.

Figure 2 illustrates this overlap in goals for collaboration in class. Ms. Hamilton and her students each find working with others to be of value. However, the purpose of that collaboration appears different in their respective reflections. We see these diverging goals as a potentially more significant barrier than the differential goals around epistemic agency. The view of science as looking for a single right answer works against the incremental view of building better explanatory accounts over time that motivates the collaborative approaches of putting partial ideas together and exploring competing ideas that Ms. Hamilton encourages in her students. This difference in emphasis can lead both teacher and students to focus energy on different goals, each of which can leave the other goal unmet. For example, if students continued to ask one another if they know the answer rather than comparing ideas and assembling a consensus, students may have felt frustration because no one "knows the right answer," At the same time,

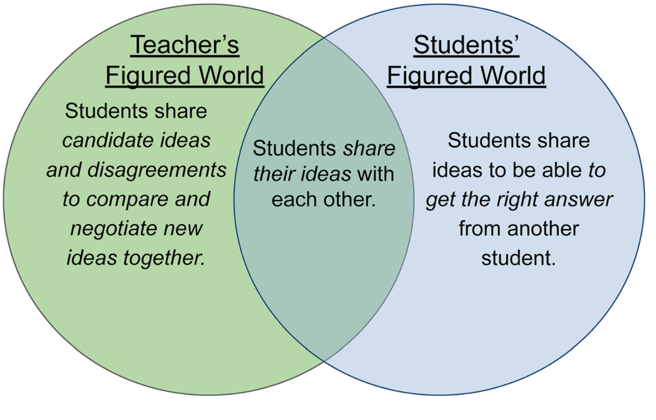

FIGURE 2 Comparing collaboration goals for class.

Ms. Hamilton may have felt frustrated because students were resistant to share their emerging ideas because they thought they were "wrong."

4.2 | Issue 2: Tensions due to varying expected roles in class

Another salient feature of figured worlds is that of the significance assigned to certain acts (Holland et al., 1998). We combine this with the way Munson (2021) discusses roles in a figured world and examine the ways both Ms. Hamilton and her students assign significance to the roles or actions of classroom members.

4.2.1 | Expected teacher's role

As seen in the data regarding goals for class presented above, Ms. Hamilton sees part of her job is to elevate student ideas (SR1-L1; L1 transcript), direct students in considering the ideas of others (SR1-L1; SR4-L12; L4, L12 transcripts), and assist students in following the collective sensemaking of the class (SR1-L1). Additionally, she mentions using questioning techniques to push student thinking rather than evaluating student ideas as correct or incorrect (SR3-L9). As an example, Ms. Hamilton recounts these ideas she shared with the class:

> Try your hardest, let's learn together. Nobody's idea is dumb or stupid. [...]. We have to work together to figure this out. I'm not going to tell you the answer because that's not how life is. (SR2-L4)

Ms. Hamilton makes it clear she does not see her job as just to "tell" students answers. Instead, she says that her job is to work together with students to figure out science ideas. This idea of working alongside students was evident in other reflections as well.

> I don't see myself as kind of their teacher, [...] but I would like to see it as more of like a mentor and a person who's helping them, not telling them what they have to learn and how they have to learn it but guiding them. (SR4-L12)

Ms. Hamilton reveals she sees part of her job as relaxing control of where the lesson goes or what the students talk about. She identifies herself as a mentor or guide to help students take up new ideas and encourage students to share their ideas so that they can be publicly considered. She does not see it as her job to tell students the right answers, what to do, or the way to learn science ideas.

This is the one instance from the teacher's stimulated recall interview reflections we were not able to identify explicit teacher statements in the stimulated recall lesson transcript that illustrate the teacher discussing this position with students (although her questions certainly seem consistent with this view of collaborative and incremental knowledge building). However, the stimulated recall transcripts are based on less than an hour of classroom observation data spread across five lessons. It is possible that Ms. Hamilton's sharing with students does or does not convey these messages as clearly as she perceives, but our data do not allow us to support or negate this claim directly.

Conversely, the students place large expectations on Ms. Hamilton in their mastery of science knowledge. We found that five out of six student interviewees express the idea that it is Ms. Hamilton's job to explain ideas and answer their questions (SI1, SI2, SI3, SI4, and SI6). They make comments about expecting the teacher to "reword" her explanations, "break down" the ideas, or "show" them (SI1). Additionally, Ms. Hamilton is viewed as the ultimate source of knowledge: "Some questions are like nobody knows the answer [...] so then I'll ask Ms. Hamilton" (SI3). Further, the students express frustration when they think the teacher does not fulfill these roles adequately.

> If she would reword it or break it down even more, then I would get to understand it even more because when she says it, I can't really understand it. (SI1)

> Sometimes she doesn't explain it in a way I can understand it. She'll be like, she'll ask a question and then I'll be like (shrugs) and then she'll explain the question and I still don't understand it. So if she don't explain it to where I understand it, I'll ask another classmate (SI4)

When asked about the "hints" that Ms. Hamilton sometimes gives to help students figure out science ideas, SI6 says: "To me, they kind of seem off topic. Like they don't really help me out as much as I expect them to." These comments indicate that the students do not recognize Ms. Hamilton's expectation for them to figure things out for themselves and her intent to provide guidance rather than answers.

Another teacher role students name is that of making science class interesting and related to life outside of the classroom, and multiple students note that class was sometimes boring. For example, "It got boring somedays in class" (SI5) and "It kind of got boring because she wasn't explaining it as interesting" (SI3). Related, students see the teacher as the one in charge of directing the pace of class to help address potential boredom. "Give [us] a time limit and we'll stick to it. Give us a schedule so we can keep the flow so [the unit] doesn't run late" (SI1). This student expands on how class can be more interesting to her:

> I really like to think of life as math, science, reading. I want to know that there is a purpose of you teaching me this so I can go out into the world and know, oh yeah, that's what Ms. Hamilton said.

Figure 3 illustrates the disconnect between what Ms. Hamilton expects from herself in class and what her students expect from her. All members of the community expect the teacher to structure and guide class conversations and activities, but the way this should happen varies from different perspectives. Students largely ask for help from the teacher, expect clear and complete answers, and hold on to the transmission-based approach to roles—where the teacher tells students what to do, explains science concepts, and, to some extent, keeps them engaged so that they avoid boredom in class. Ms. Hamilton says that her intention is to create spaces for students to act as epistemic agents in building science knowledge. She works to elevate student ideas, prompt students to wrestle with various ideas, build on each other's ideas, and guide conversations in general ways. Yet the students do not recognize that as part of her role. This mismatch leads to student frustration as seen in our data and is consequently also related to some frustrations in unmet expectations for student roles as well.

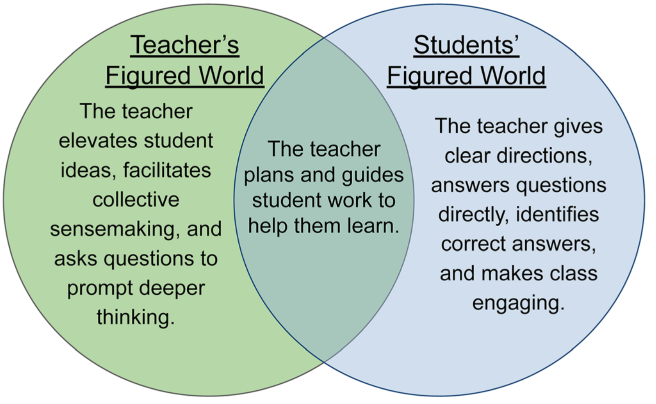

FIGURE 3 Comparing teacher roles.

4.2.2 | Expected student roles

As seen in the data regarding classroom goals, Ms. Hamilton consistently indicates that students should contribute to class conversations (SR1-L1; L1, L4, L12 transcripts), share ideas (SR3-L9; L4, L12 transcripts), and ask questions (SR4-L12). She expects students will be active participants in figuring out science ideas. When stating that "Nobody's idea is dumb or stupid, we're just going to try to figure it out together" (SR2-L4), Ms. Hamilton implies she is not looking for students to share completely "correct" or "right" ideas—just that they share so that sensemaking can progress. These data show that Ms. Hamilton desires a classroom environment where her students take "ownership" of their learning and have agency in their contributions.

> [I'm] not telling them what they have to learn and how they have to learn it, but guiding them into like, "hey, have you ever thought about this?" Or "oh, let's think about that." And I've done that a lot. And it puts a lot of the onus on the kids. [...] And I think that helps them become better group members but also independently thinking. And taking ownership. (SR4-L12)

These expectations for students are in line with an incremental sensemaking approach to science class and pair well with the role Ms. Hamilton describes for herself in class. She sees herself more as a guide and wants students to be able to do much of the work to investigate and make progress with their own science wonderings.

Similarly, Ms. Hamilton's students talk about listening to one another (SI2; SI5; SI6), asking questions (SI1, SI2; SI5), and connecting their ideas to the ideas of others (SI4). However, in contrast to Ms. Hamilton's desire for students to share their thoughts in order to develop consensus on science ideas, students' comments are consistent with their view of the goal of working together in class. Specifically, the student interviews reveal that the students largely think their expected contributions to class are to provide "right answers" to questions or to find "right answers":

> I try my hardest to participate if I know the answer. Like if I don't know the answer, then I'm not going to ask. [...] If I don't know it, I'm pretty much going to

be wrong, so I might as well just hear other people out and see where they're coming from and see how it works. (SI1)

Students indicate that they know they should contribute to class discussion, but they do not seem to have taken up the concept of sharing their developing ideas, whether they are completely correct or not. Students consistently use language around getting right answers rather than sharing about how the class figures things out together.

I'll ask other people how did you get this and how did you get that? (SI1)
We asked for help and she told us, but then we still kinda couldn't get it (SI2)

These comments suggest that students see part of their role is to work collaboratively and help one another, but toward the end of getting correct answers rather than making sense of ideas together, connecting back to varying goals for class among teacher and students. Similar to the synergistic nature of Ms. Hamilton's expectations for herself and her students, the students' expectations for themselves and for Ms. Hamilton pair well with each other. The students seemed to see their role as gaining the correct information, and they tended to see Ms. Hamilton's responsibility as giving that information to them. While Ms. Hamilton expects her students to contribute to class, even when their ideas are incomplete or even potentially wrong for the purpose of making sense of ideas together, the students seemed hesitant to participate in class when they do not have a firm understanding of concepts or do not know how to answer questions. The idea that the purpose of conversation is not necessarily to find the "right" answer appeared at least somewhat foreign to students and emerges explicitly as they push back against the teacher's encouragement and directions.

Figure 4 illustrates this comparison between the teacher and student perspectives on the students' role. Like the other elements of figured worlds addressed above, there are some ways in which expectations for student roles in class are similar across the teacher and student figured worlds, but individual reflections reveal that the way each expects those roles to play out are actually quite different. When the teacher works to create conditions for students to act in certain ways and when students contribute to class in different ways, it can be difficult to attain class goals. In addition, this can lead to increased tension in the classroom as each member of the community puts forth effort to fulfill expectations that are not common across the group.

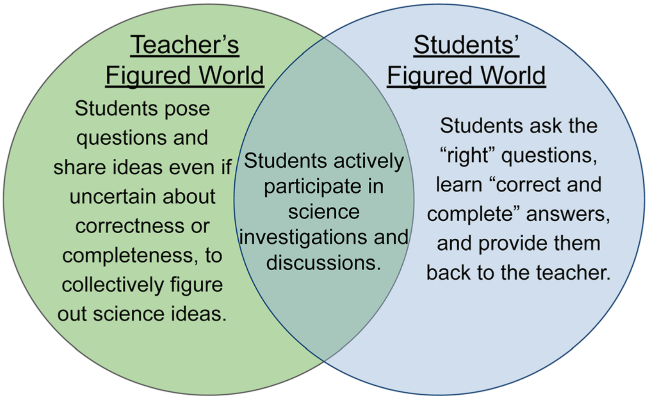

FIGURE 4 Comparing student roles.

4.3 | Addressing tensions between the figured worlds of the teacher and students

The figured worlds framework allows us to identify how members of the classroom community may value different outcomes or goals for class and potentially have variable expectations for the roles of individuals. This framework also provides a way to identify the differences and potential sources of conflict that can occur because of variable expectations for the classroom space. Now that we have identified key tensions in the roles and expectations that emerged between the teacher and students, we turn to how the teacher attempted to address them. A first step is recognizing these different worldviews underlying the issues experienced in their interactions. Ms. Hamilton recognizes the difficulty in transition for her students. She reflects:

> I feel like my classroom is unstructured but it's structured. [...] It is very open and free, but it's in a structured way and the kids are not used to having the freedom but in a structured way, and they sometimes have a difficult time with that. (Pre-Enactment Interview)

As a result of recognizing these difficulties, Ms. Hamilton does some work to help her students understand her goals for class. She reports telling them things like "My questions are for you guys to think about it a little bit deeper or to make you think in a different direction" (SR1-L1) and "You have to work together to figure it out" (SR4-L12). While these statements appear to reflect Ms. Hamilton's expectations, they are not explicit in pointing out that she recognizes her student are thinking differently or helping cultivate buy-in to this different approach. As a result, they may leave students a bit in the dark as to how the goals of class may not be what they expect them to be. In some ways, Ms. Hamilton is better equipped to navigate the tensions in class due to her prior experiences teaching this way. As she shared in an interview, it is because of these experiences that she has some confidence that things will improve over time:

> That first half 'til midterms is a struggle. Just getting them used to being able to figure it out on their own and not looking to me for answers. [...] Usually second quarter they're like, we know you're not going to give us the answer, you're going to ask us what do you know? Ask a teammate [...], and I'm like "But if we get stuck, like I'm here to help you, you know maybe with some different ideas." Like "Oh, have you ever thought about doing it this way, you know." (Pre-Enactment Interview)

Ms. Hamilton is able to press on after that difficult day in the unit when students express they "hate" her class because of her prior experience teaching students through a sensemaking figured world of learning science. Her experience tells her the students will eventually see their learning and have ownership over that learning. Indeed, by the end of the unit, she recognizes the fruit of that labor. Although this unit started with students stating "I don't want to learn this. I don't want to learn this kind of science. We hate this class" (SR1-L1), it did result in some success. During the final lesson of the unit, Ms. Hamilton had the class reflect on their learning during the unit:

Ms. Hamilton: How do you feel now that you know it's not just "this cup works better [than this one]?"
Student: Smarter than a 5th grader.
Ms. Hamilton: Why do you feel like you're smarter than a 5th grader?
Student: Because from 5th grade science to this, I feel like I never learned anything new.
Ms. Hamilton: OK so what is new about what we learned? [...] Why do you feel smarter? [...] Do you understand it's not just cups?
Student: Because now we know about other little stuff that's happening. Molecules—stuff like that.
Student: And when I get asked a question, then I be knowing how to answer it. [...]
Ms. Hamilton: And one last look [at the driving question board]. Look at that. We just answered all of our questions. [...] So did we learn a lot?
Student: Yeah [...]
Student: I think you set this all up because you knew we was going to be doing this.
Ms. Hamilton: Oh I set you up? You're saying I had you guys do this because I wanted you to get here?
Student: Yeah
Ms. Hamilton: Did I tell you what questions to ask? [...]
Student: I didn't think we would get this far.
Teacher: Why did you not think we would get this far?
Student: Because I didn't think we would find [all of] this out from cups.

While reflecting on the last lesson in the unit, Ms. Hamilton shares:

> I thought it was pretty genuine about when we went back to the [driving question board] and they're like oh no, holy crap we really did learn a lot. And we actually answered all the questions that we had. And then they were questioning like how did you know? Like I remember they were like "how did you plan that we were going to actually answer these questions? It was like sorcery." (SR5-L18)
>
> Like probably 75% of the kids were just like, "WHAT?! We figured out what?" When we did the consensus model at the end to figure out everything they're like, "holy cow, we're so smart. And we did this" like taking that ownership is that next step up and just it's the light bulb, the ownership. Them, me not saying like, oh, you get an A, because you did you answer these four questions. It's them being like, "holy crap like we really figured this out, like we're really smart" (Post-Enactment Interview).

In these last moments of the unit, the students become aware of one of Ms. Hamilton's goals from the beginning—that the students would figure out the answers to their own questions about the phenomenon. The students are surprised by this accomplishment. However, after this discussion, they have the opportunity to take on the expectations for themselves to answer their own questions about science.

5 | DISCUSSION

Curriculum materials and synergistic teaching approaches anchoring students' science learning in the questions they identify have shown promise in supporting students taking epistemic agency in their science learning (Alzen et al., 2023; Penuel et al., 2022; Singleton et al., 2024). However, these shifts in norms, roles, and interactions require time to cultivate and support. The opening vignette in this article illustrates one type of challenge that can occur as teachers work to bring new forms of teaching and learning into their classrooms. This vignette and data that follow depict students actively voicing and exhibiting reluctance that pose challenges for the teacher's efforts.

We explored this resistance by examining how the teacher and students interpreted their own and one another's goals and roles and investigated how these divergent interpretations could underlie students' resistance. We applied a figured worlds framework to identify the significant acts in their context, how actors recognize one another for those acts, and the value assigned to particular outcomes (Holland et al., 1998). Identifying the explicit and tacit expectations that make up the figured worlds of the teacher and students revealed specific tensions in the ways that they conceived of themselves and each other that appear to align with the type of challenges observed.

5.1 | How does student resistance emerge and present roadblocks for learning?

Challenges in students taking up more responsibility for working as a community to build science ideas could potentially arise from students lacking sufficient familiarity with the science practices needed to make progress and finding themselves unable to succeed in the tasks as framed by the teacher. Indeed, students do mention feeling stuck and that they "can't really ask somebody" because nobody else "knows how to do it" either. However, these perceptions are accompanied by other attributions that appear to work against them eagerly diving in and embracing the potential struggles this kind of sensemaking work can engender.

Consider the implications of the four aspects of divergence we found in teacher's and students' perceptions. We see these factors working together against the teacher's desired shifts. The focus of the reforms on using science and engineering practices to build and apply science ideas relies on students taking more epistemic agency. Students are asked to engage in key elements of the figuring out as they plan how to investigate their questions, argue from evidence, and use their findings to develop and revise explanatory models. If students are skeptical that they "know enough" to take on this kind of responsibility and see agency instead as more superficial choices about which unit to do next or who to work with, they may be reluctant to take on sensemaking agency and become frustrated with classroom tasks as the teacher defines them. Thus, we see students push back when the teacher invites them to participate in intellectually risky ways such as offering draft ideas, which they do not see as their role, and complain that the teacher is "trying to make us look dumb in front of each other."

These challenges to student agency are synergistic with students' views of how science knowledge is developed. Sharing one's initial explanation for puzzling phenomena, before being confident it is "correct," takes on more social risk if one views learning as obtaining "correct answers" rather than assembling and negotiating ideas. Being reassured by the teacher's assertion that "nobody's idea is dumb or stupid" requires trusting that a community can make progress by working with multiple candidate ideas, negotiating consensus, identifying disagreements to motivate further investigation, and iteratively revising ideas over time (Affolter et al., 2022). Seeing the value of an idea as a binary choice between correct and incorrect works against the claim that one's initial intuitions for an explanation would be a helpful starting point. Thus, these students want to hold back when they feel uncertain about an explanation: "I try my hardest to participate if I know the answer" but "If I don't know it, I'm pretty much going to be wrong, so I might as well just hear other people out."

In contrast, the curriculum is designed to help students realize that they *cannot* explain the phenomenon fully at key points, in order to motivate the need for additional investigations. Consequently, the pedagogical approach of building a "need to know" from students' attempts to explain everyday phenomena they have not "been taught" (Reiser et al., 2021) becomes viewed by students as the teacher asking unexpected and unreasonable questions. This hesitation to share one's initial thinking becomes an ongoing pressure working against the sharing negotiation of ideas. Consistent with this, students see the teacher's attempts to help through hints as "off topic" and suggestions that "don't really help," perhaps because her hints focus on possible next steps in figuring out rather than hinting toward an "answer."

Similarly, the idea of working as a collective group of students to build upon each other's ideas is more appealing when one views knowledge as being assembled and negotiated, rather than identifying who has the right answer. When students see their role as obtaining correct answers, listening to other students becomes an opportunity to get correct answers rather than to build on each other's thinking and construct something that goes even further. The strategy of building a meaningful context for scientific argumentation from the emerging disagreements between students' ideas and identified gaps in what they can explain faces challenges when students are skeptical of the benefit of collaborating to develop further investigations that can refine their ideas.

The students' views of the teacher's role cohere with their views of their own roles. Students' views of their learning assume a role for the teacher as the agent primarily responsible for learning. They see her job as providing "clear directions" and "clear information," and become frustrated with her more open-ended questions and tasks that ask students to develop explanations and models. Instead, what students see as the teacher relinquishing some of her responsibility, the teacher sees as "opening up" valuable opportunities for students and expresses frustration when they do not see it that way. This creates tension with several aspects of both agency and collaboration. One can imagine students' reluctance to pose questions used to determine the course of learning when they expect the teacher to direct that learning, and to be reluctant to develop initial models when they see it as the teacher's responsibility, not theirs, for figuring out how the science works. The tension surfaces in episodes of verbal resistance when students push back asking for "more clear directions."

5.2 | Why does resistance center around agency and collaborative sensemaking?

While both the teachers and the students attended to student agency and collaboration, it is in the details that we found differences. Specifically, students saw agency as something that is less about knowledge building and more about choice in participation structures and social interactions. They recognized the opportunities for agency that the teacher was trying to provide but ascribe different meaning to those actions. Further, students did not appear to trust that the collective work could provide opportunities for building something together that would not have been possible alone. These views were echoed in how they saw classroom roles. We found that students were more focused on the teacher as the one who controls the direction and substance of science, rather than seeing her as a facilitator for knowledge building. They recognized the need to be active participants in the class but viewed it as complying with the teacher's directions to work together.

We suggest that the elements emerging in this analysis became core tensions because these are central points of divergence between the epistemic aspects of the figured world in the curriculum and teacher's sensemaking approach with the "transmission" framing of school students brought from their experience (Richmond & Wray, 2023). Building knowledge incrementally, through investigation, argumentation, and consensus building as a community rests on key differences in the epistemic agency expected of students and the need for students to work as a collective. This becomes expressed as conflicts in the students' and the teacher's roles, in the expectations for students' work, and in how students collaborate. While other aspects of the science approach may also seem new, these arose as key tensions.

6 | IMPLICATIONS

As Munson (2021) states, "pedagogical change is not linear, stepwise, smooth, or speedy" (p. 647). We need to be prepared to respond to roadblocks for teachers and students that occur in transitioning to a sensemaking approach. Indeed, supports for teachers and students in this process have been part of the curriculum materials, classroom tools, and professional learning design and investigation in achieving the goals of the framework (National Research Council, 2015). Next, we explore the implications of our findings to identify potential areas for design and research.

6.1 | Explicit and ongoing attention to the changing nature of the school game

It is increasingly common to include classroom norms or classroom agreements as part of kicking off one's classroom each year that address issues such as ways of working together. We suggest this takes on special significance when the science reforms include shifts that challenge current expectations about how teachers and students will interact. In some classrooms, introducing agreements like this may take the form of an initial discussion or two at the start of a year, or a single lesson at the start of a new reform-based unit. These norms may consist of general guidelines such as "be respectful while still being critical." We suggest that cultivating a classroom in which science practices are meaningful to students requires two additions: (1) *directly link classroom agreements to students' own science sensemaking goals* and (2) commit to *ongoing monitoring and revision* of how classroom agreements are affecting the work.

Meaningful practice requires that students see the need for what the classroom is working on (the questions and problems) and how the community does that work (building knowledge through the science and engineering practices) (Miller et al., 2018). The goal is not to have students use evidence to support claims simply because "that's what scientists do," or because it fits what "the teacher wants us to learn." Cultivating the need for learning more about a problem is a hallmark of situating science learning in real world questions and problems (e.g., Miller & Krajcik, 2019). However, involving students in identifying the need to engage in particular sensemaking practices, and helping students build those practices is more difficult (Bang et al., 2017).

We see a key need for curriculum materials and teaching approaches to cultivate buy in for the questions and problems the class takes on, and to engage students in figuring out how to structure their own sensemaking in ways informed by the discipline but meaningful to the classroom community (Berland et al., 2016; Krist, 2020). To accomplish this, we argue that general agreements such as "be respectful," while a productive step, does not sufficiently motivate or guide student participation. While such norms state what to do so as not to discourage others from participating (e.g., "critique the idea and not the person"), it may fail to identify the expectation that all participants contribute. Cultivating the willingness to contribute draft thinking requires more than cautioning students against behavior that discourages participation; it requires helping students see why participation by sharing draft thinking is necessary for the community to make progress (Michaels & O'Connor, 2012). This requires making that expectation explicit ("we share our own thinking to help us all learn") and helping students recognize how a classroom sharing their draft thinking helps them learn (Affolter et al., 2022).

Additionally, establishing meaningful practices requires more than identifying expectations, it means delivering on those promises (Alzen et al., 2023). A key point in transitioning figured worlds is for individuals to not only author themselves into roles and responsibility but for others to reinforce those roles (Eisenhart & Allen, 2016). Regular space to reflect on the transition creates opportunities for both teachers and students to identify difficulty points or mismatched expectations, and potentially negotiate adjustments to the expectations (Holland et al., 1998; Price & McNeill, 2013). Strategies for curriculum materials and teaching approaches are needed to help the classroom monitor agreements and help students see how they pay off (Affolter et al., 2022).

6.2 | Limitations

We have taken a broad strokes approach in applying figured worlds to identify points of convergence emerging among multiple students in this classroom. This figured world lens is useful to explain central points of tension between Ms. Hamilton's views and many of her students' views about key aspects of their science community. However, this experience likely varies somewhat across students and across time. Munson (2021) suggests reform-oriented classrooms are likely to contain a mixture of students who transition alongside the teacher, resist, and find themselves in the middle. Our analyses examined only a subset of students, and did not focus on uncovering this nuance and variability. Further research is needed to examine how variation in students' experiences may emerge, and how their figured worlds may shift over time. In addition, we did not originally develop the methodology for this study to explore figured worlds. Our retrospective student interviews did uncover important aspects of how the teacher and students viewed their roles, and helped identify points of tension. More direct questions concerning students' goals and roles would be useful in future work, as would examining more student voices and more time points along the unit.

7 | CONCLUSION

Teachers and students who work to transition their classroom to more reform-oriented practices experience various successes and challenges. Analyses of the figured worlds of these participants highlights how fundamental changes in the tacit rules that drive classroom engagement can lead to resistance and frustration. This may occur even when these aspects are linked to what the reforms frame as benefits for students—namely increased agency, connection of the science to learners' own lives, and experience building knowledge in a community. This work calls out the importance of identifying points of tension and addressing them in design so that tasks, classroom tools, and teaching approaches help cultivate these shifts over time in meaningful ways. Our goals for more meaningful science for teachers and students cannot be achieved by mandating new curriculum approaches and expecting students to take on these new practices because "this is what scientists do" or "this is what our new standards or teacher wants." While targeting agency and collective sensemaking has great potential, the participants of the classroom community must be part of constructing and enacting these practices in ways that are compelling and meaningful to them.

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CONFLICT OF INTEREST STATEMENT

The authors report there are no conflicts of interests to declare.

DATA AVAILABILITY STATEMENT

The data are not publicly available due to privacy restrictions.

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