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Developing Science Classroom Expectations That Encourage Risk-Taking for Learning Science Together

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ABSTRACT

Reform-oriented science classrooms encourage environments in which students engage in a collective enterprise of making sense of their science ideas together. Teachers who strive for these sorts of environments support students in collaboratively constructing and answering their own questions about phenomena and making sense of competing ideas together. However, to engage with one another productively, students must ask questions, share incomplete thoughts, and comment on each other's ideas, all of which can be seen as risky and unfamiliar behavior that may result in feelings of uncertainty or other negative classroom consequences. We conduct an explanatory case study using student and teacher interviews, teacher surveys, and classroom video collected over 2 years to investigate how one teacher used classroom norms to establish and maintain a culture in which students appeared committed to taking risks to improve their collective knowledge-building. We found that norms were one practical tool the teacher used to encourage students to take risks and that also seemed helpful for negotiating individual and group uncertainty. Norms were also tools the teacher used to ensure that she and her students had similar expectations for classroom engagement. This study practically addresses some key challenges teachers face in enacting reform-oriented science teaching and offers suggestions for how continued research regarding norms and uncertainty can continue to further science reform efforts.

Reform-oriented science classrooms are those in which teachers and students construct science knowledge through collaborative engagement in the science and engineering practices (National Research Council 2012; NGSS Lead States 2013). These practices include activities such as asking questions and defining problems, developing and using models, planning and carrying out investigations, constructing explanations, and engaging in argument from evidence (NGSS Lead States 2013). Such engagement is central to science education reform as it prioritizes incorporating various viewpoints and experiences to develop robust science knowledge (Carrier 2013; Erduran and Dagher 2014; Longino 1990).

In reform-oriented science classrooms, students develop questions about phenomena and problems, identify how to investigate and find answers to those questions in ways that make sense to them, and collaboratively develop science ideas that build from their collective prior knowledge and experiences (Berland et al. 2016; Damşa et al. 2010; Schwarz et al. 2017; Stroupe 2014). For students to take on these roles, many teachers need to adapt their practices to give up positions as primary owners and distributors of knowledge and shift more responsibility to students to develop and construct their own understanding of science ideas with their peers (Miller et al. 2018). Additionally, for students to truly consider one another's

ideas and experiences as they develop their science knowledge, they must be willing to engage in potentially risky behavior such as sharing emerging thoughts and uncertainty or challenging others' ideas that could result in being rejected or being positioned by peers or the teacher as less capable (Beghetto 2009; Cetin et al. 2014; Mitton and Murray-Orr 2021). Both teachers and students need to shift their engagement with one another and subject matter to support this type of environment (Carrier 2013; Damşa et al. 2010; Ke and Schwarz 2021; Manz et al. 2020). Indeed, when they do not make these shifts in tandem, conflict can arise due to inconsistent expectations for one another (Alzen et al. 2024).

In this paper, we explore one teacher's approach to reform-oriented science instruction and study how she used classroom norms to create a classroom culture in which her students appeared willing to take risks to engage in a collective enterprise about building science knowledge together. We begin by examining her students' reflections about their experiences to establish that they describe class as a place where they strive to work together to figure out science ideas. Then we turn to a specific classroom episode to identify a clear instance where students took risks, the class responded to those risks in ways aligned with the classroom norms, and the group's learning moved forward as a result. Finally, we consider how the community's practice of goal setting related to norms may have prepared students for navigating uncertainty in moments such as the one presented. The current work not only contributes to the literature regarding reform-oriented science classrooms generally but also expands the literature around specific strategies and tools to support reform-oriented science classrooms in which students are encouraged and motivated to take risks to engage in science knowledge construction.

1 | Conceptual Framework

A robust body of literature establishes the centrality of epistemic agency and collective enterprise in reform-oriented science classrooms. If students are in charge of posing questions, planning investigations to answer their questions, and using collected evidence in arguments about their ideas, then they have the authority to take an active role in knowledge construction through opportunities for epistemic agency (Berland et al. 2016; Damşa et al. 2010; Miller et al. 2018; Stroupe 2014). Teachers support students in a collective enterprise of building science ideas together when they encourage students to exchange ideas, build on one another's thoughts, make sense of competing ideas, participate in respectful public argumentation, and reach consensus as a group (Carrier 2013; González-Howard and McNeill 2019; Reiser et al. 2021; Scardamalia and Bereiter 1991). In prior work, we developed conjectures about how students' levels of epistemic agency may be expanded or limited by the extent to which teachers encourage and support students in engaging in a collective enterprise of developing science knowledge together (Alzen et al. 2023). We then studied how differences in teacher and student expectations for themselves and others around the roles they play in pursuing a collective enterprise can be a barrier to maintaining a reform-oriented classroom (Alzen et al. 2024). In this study, we further develop our conjectures about supporting reform-oriented classrooms by investigating the nuanced ways teachers can leverage norms to facilitate a classroom commitment to a collective enterprise by supporting students in intellectual risk-taking over time.

We begin by reviewing the role of the collective enterprise of sharing, constructing, and refining ideas together in science education. We start with collective enterprise, the commitment to building knowledge together, as it is an element we argue is necessary to authentically engage students in the science practices and is central to interpreting what we observed in our data. We also describe the overlap between student classroom contributions necessary for this collective enterprise and the concepts of intellectual risk-taking and uncertainty. Finally, we focus on research regarding classroom norms and expectations, as norms are a key element of the curriculum used in our focal classroom and are central to the approach our case study teacher used to encourage students to take risks and actively contribute to group knowledge-building work.

1.1 | Commitment to a Collective Enterprise, Intellectual Risk-Taking, and Uncertainty

A classroom community is committed to a collective enterprise of building science ideas when its members prioritize "collaborative idea production" (Damşa et al. 2010, p. 152) to construct and answer their own questions about phenomena and build explanations about the world (Erduran et al. 2018; Schwarz et al. 2017). Such commitments reflect the value placed on multiple perspectives for developing science knowledge (Carrier 2013). To support this collective knowledge building and subsequent revision of ideas, teachers elevate and center student ideas, support productive argumentation when ideas differ, facilitate identification of areas of agreement and disagreement, encourage students to draw upon shared classroom tools and artifacts to justify ideas, and guide students in building and revising models to represent the class's current understanding (Alzen et al. 2023; González-Howard and McNeill 2019; McGinn et al. 1995; Reiser et al. 2021).

When teachers facilitate collective knowledge-building work, they ask students to share untested or first-draft ideas, ask questions, and potentially challenge majority viewpoints. Prior research defines such activities as intellectual risk-taking (Beghetto 2009; Cetin et al. 2014; Clarke 2015) because engaging in these actions could produce undesirable outcomes including being dismissed or ridiculed, receiving negative criticism, or being perceived as having a lack of understanding (Beghetto 2009; Byrnes et al. 1999; Lemos 2002; Varışoğlu and Ekinci Çelikpazu 2019). Such actions likely seem particularly risky when years of prior school experiences have reinforced the ideas that teachers do not necessarily value incomplete thoughts, that teachers regularly identify and correct mistakes, and that some teachers prefer students compliantly receive knowledge rather than question prevailing ideas (Makar et al. 2015; Wright et al. 2018).

The actions often required for engaging in a collective enterprise can also be cast as risky because of the ways they may cause students to experience feelings of uncertainty. We take up

Jordan and McDaniel (2014) definition of uncertainty as "an individual's subjective experience of doubting, being unsure, or wondering about how the future will unfold, what the present means, or how to interpret the past" (p. 492). When students take risks to share incomplete ideas or challenge majority viewpoints, they may feel unsure about how their ideas will be received and how their peers or their teacher will react. That uncertainty may be felt by students wondering if their ideas are "correct" or if the ways they interact with peers, the teacher, and even the content are viewed as correct performance for classroom participation as the methods of classroom engagement in reform-oriented classrooms are often different from prior experience (Alzen et al. 2024; Jordan and McDaniel 2014; Starrett et al. 2024). Traditionally, teachers and students often look for ways to avoid uncertainty (Manz and Suárez 2018; Radinsky 2008; Starrett et al. 2024). However, "uncertainty is a universal attribute of science" (National Research Council 2012, p. 44), and engaging in the science practices ensures activities in which individuals must work through uncertainty (Manz and Suárez 2018; Starrett et al. 2024).

Due to the potential risks associated with the kinds of student participation necessary for collective knowledge-building work and the consequential feelings of uncertainty, convincing students that such engagement is worthwhile can be challenging. Although prior research on intellectual risk-taking and uncertainty documents their existence in reform-oriented science classrooms and discusses the need to encourage such classroom contributions, the literature also calls for more work that identifies specific teacher moves and tools that can be used to encourage such classroom participation (Beghetto 2009; Mitton and Murray-Orr 2021). Some researchers even argue that teachers should use feelings of uncertainty as a resource for learning (Chen 2022; Jordan and McDaniel 2014; Starrett et al. 2024). We conjecture that classroom norms may be a useful tool for both encouraging students to take intellectual risks and to navigate their feelings of uncertainty both as individuals and as a group.

1.2 | Classroom Norms and Expectations

School and classroom culture involves multiple processes that influence students' school experiences and motivation to participate in particular ways (Cavanagh and Waugh 2004; Yackel and Cobb 1996). Classroom culture includes elements such as relationships, procedures, participant structures, routines, values, and physical and non-verbal cues (Bennett 2014; Carlone et al. 2011; Ruiz-Primo and Furtak 2024). This culture is initiated at the start of the school year and is cultivated in implicit and explicit ways over the course of the year. A safe and engaging classroom culture enables students to feel connected to their classroom community and successful in their participation within the community (Ruiz-Primo and Furtak 2024). Further, such an environment supports students in taking risks and sharing their uncertainty with others (Jordan and McDaniel 2014). In reform-oriented science classrooms, the teacher can work to establish and maintain a classroom culture in which students are invested in the learning environment and are prepared to take on the different roles and potentially risky expectations necessary for both the teacher and students to engage in a collective enterprise around science ideas. For example, students may need support in questioning or challenging one another's ideas if they are unsure or do not agree rather than working alongside one another to find right answers or complete discrete tasks (Alzen et al. 2024).

In previous work we found that alignment between students' and teachers' expectations for themselves and one another is an important factor in facilitating the shift from a didactic environment to one in which the students both understand how collective knowledge-building occurs and find the endeavor worthwhile for their learning (Alzen et al. 2024). Specifically, we identified that when teachers and students have different ideas about the goals for class and the roles the teacher and students should play in pursuing those goals, it is more difficult for the class to successfully engage in the science practices. For example, if teachers expect students to share emergent or incomplete ideas for the purpose of making sense of them together (a potentially risky behavior), but students expect they should only share ideas they believe are fully formed and correct, gridlock may occur during classroom discussion. In this paper, we focus on classroom norms as one aspect of developing a classroom culture that the teacher can influence at the beginning of the year and leverage as a tool to maintain consistent expectations for goals and roles within the classroom. More than that, we argue that norms can be a tool by which teachers both elicit risky behaviors from students and offer to students as a way to negotiate any resulting feelings of uncertainty.

We argue here that the creation and maintenance of shared classroom norms was an important influence on students' motivation to engage in a collective enterprise of building science ideas together in our focal classroom. We define norms as the "classroom level cognitive and social structures operationalised through the collective expectations of the teacher and students about what counts as appropriate activities and interactions" (Makar et al. 2015, p. 1108). We acknowledge that members of the classroom community may hold varying expectations for themselves and one another of which they are unaware (Yackel et al. 1991), so we use the term classroom norms in our study for those expectations that the members of our focal classroom community made explicit and aspired to hold common among themselves.

We do not take up a definition of norms that derives from recognizing normative patterns across classroom interaction (i.e., identifying commonly occurring interaction patterns among members of the classroom community) that might be superimposed by the teacher alone or from the dominant community represented in the classroom (Cobb 2002), but we do suggest that teachers have a role to play in establishing initial ideas for norms and expectations about which the classroom community can negotiate, particularly when expectations around teacher and student roles in the classroom may be different from students' prior experiences (Alzen et al. 2024; Cobb et al. 1989; Yackel et al. 1991; Yackel and Cobb 1996). Such is the case in many classrooms where a teacher desires to establish a classroom culture in which students commit to a collective enterprise around building science knowledge because supporting such work asks that students

participate in potentially unfamiliar ways (Alzen et al. 2024). Teachers can use their positions in the classroom to suggest norms around ideas such as risk-taking, curiosity, and negotiation to help students recognize these expectations as fruitful for their learning, even if they might initially seem unusual (Cobb et al. 1989; Jordan and McDaniel 2014; Makar et al. 2015; Makar and Fielding-Wells 2018).

In our working definition of norms as "collective expectations about what counts as appropriate" (Makar et al. 2015, p. 1108), we also acknowledge that both implicit and explicit norms are laden with values about the discipline and disciplinary learning and can shift over time as individuals learn, grow together, and potentially change their ideas about expectations for themselves and one another (Cobb 2002). Thus, part of a teacher's role in the classroom is to establish, display, remind, and potentially facilitate renegotiation of classroom norms and expectations to create a culture necessary to support high levels of student engagement (Cobb et al. 2009; Makar et al. 2015; Yackel and Cobb 1996). However, simply having norms or even returning to and revising them does not ensure full student participation, nor does it guarantee that students will engage in collective knowledge-building work (Chang and Song 2016; Makar and Fielding-Wells 2018). Classroom norms may not be consistently taken up by students (Chang and Song 2016), and many factors can influence how students internalize norms including understanding, interpretation, and alignment with students' beliefs or habits (Chang and Song 2016; Makar et al. 2015). Additionally, the ways teachers create, enact, and encourage norms also influences students' perceptions of norms (Turpen and Finkelstein 2010). However, despite these variations, we argue that norms can facilitate student take up of deep engagement with disciplinary ideas and practices in the classroom and that there are particular teacher moves in creating, enacting, and supporting those norms that may more readily encourage students to participate. Thus, we oriented our analysis around the research question: "*In what ways can classroom norms support students' intellectual risk-taking and collaborative knowledge-building around science ideas?*"

Note that we did not directly investigate student feelings of uncertainty, rather the attention to this feature of the classroom was emergent from our analysis of the relationship between norms and collective knowledge building. We conjecture that our focal teacher's purposes behind, consistent use of, and involvement of student voice in establishing and upholding classroom norms creates a classroom culture in which students are comfortable engaging in intellectual risk-taking and that the classroom community's shared expectations for involvement in building science knowledge together are worthy of their contributions.

2 | Methodological Approach

We use an explanatory case study chosen as a paradigmatic case to illustrate the potential of supporting a collective enterprise through the establishment, use, and maintenance of classroom norms. Our study focuses on one teacher, whom we refer to as Ms. Seaborn, and her 7th-grade science students from two consecutive school years (2021–2022 and 2022–2023). At the time of data collection, Ms. Seaborn had 15 years of experience and taught science in a large suburban district in a west-coast state. The school enrollment comprised 85% students of color, approximately 66% students who came from economically disadvantaged households, 26% who were English language learners, and 18% who were students with disabilities. During each year of the study, Ms. Seaborn's class included approximately 30 students with a demographic makeup similar to that of the school.

2.1 | Data

Our data come from a larger research project about teacher beliefs and practices that influence enactment of curricular materials. Teachers attended a week-long professional development workshop focused on target instructional approaches and use of curriculum materials that reflect these approaches. Teachers then participated in virtual study groups during curricular enactment to identify common challenges and work together to address them in their classrooms. In our larger project analysis, we noticed the purposeful ways Ms. Seaborn facilitated whole-group discussion very similarly to how prior research describes strong interaction between both collective enterprise and epistemic agency in practice (Alzen et al. 2023), but we also observed distinct moves she made to enact and maintain norms that we argue promote student engagement in a collective enterprise. Specifically, she seemed to leverage classroom norms for the purpose of encouraging students to take risks in the ways they participated in discussion. Ms. Seaborn offered us the opportunity to present a case study that helps elaborate our developing theory (Eisenhardt 1989) about how teachers can enact reform-oriented science classrooms (Alzen et al. 2023, 2024).

To construct the case, we drew on multiple data sources collected across the two school years including teacher surveys and interviews, classroom video and artifacts, teacher stimulated recall interviews based on the same classroom video, and group student interviews. Teachers were asked to complete surveys on five occasions: before the professional development, mid-year during each year of curriculum enactment, and end of school year for each year of the study. The initial survey asked teachers about the practices they wanted to learn more about or incorporate more into their classrooms, why they wanted to incorporate those practices, and struggles they may have had with those practices in the past. The subsequent surveys asked teachers to reflect on changes they made in their practices (e.g., 'What has been your biggest area of growth this past year?'), the curricular materials used to support those changes (e.g., 'Describe a specific example or teaching moment that can help us better understand how [curricular resource] helped.'), and what they saw as next steps in developing their practice (e.g., 'What is your next step in your teaching for increasing students' sensemaking?'). Following each of these surveys, we asked teachers to reflect on key items in brief interviews. Teachers also completed daily exit tickets during the professional development where they reflected on their learning from the day, what they wanted to try in their classrooms, and what they thought might be challenging.

Researchers visited Ms. Seaborn's classroom for a week at four different times over the course of the study fall 2021 (FA21), spring 2022 (SP22), fall 2022 (FA22), and spring 2023 (SP23) as she taught the curriculum that was the focus of the professional learning program. Visits occurred approximately two-thirds of the way into the units to maximize the probability of observing students working to build consensus about their ideas and engaging in whole group discussion. Video recording, artifact collection, and three types of interviews occurred during these site visits. During daily debrief interviews, we asked Ms. Seaborn to reflect on how the day went, any changes she made on the fly from her plan for the day, moments of struggle, and plans to change things in the future. During stimulated recall interviews, occurring once per visit and twice in SP23 ($N = 5$), Ms. Seaborn watched video of a whole-group discussion and stopped the recording whenever she felt something of interest happened. She then reflected on that moment.

We also interviewed students in groups approximately 2–3 times during each classroom visit, for a total of 14 group interviews over the 2 years. Interviews typically included 2–4 students and occurred during lunch and after school. For each interview, we gave Ms. Seaborn a list of consented students and asked her to invite students who she felt represented a range of participation and achievement patterns. During interviews, we asked students about their experiences in class generally (e.g., 'Tell me about the unit. What are you learning? What's going on?'), how their current class compared to past classes (e.g., 'How does your experience in this class compare to your previous science classes?'), as well as about more specific things that were helpful or challenging about class (e.g., 'Are there times when you felt lost or confused? Is there anything that could be improved in class?'). These data were used to characterize student experiences in Ms. Seaborn's class in their own voices. We conducted one final interview with Ms. Seaborn following completion of data collection and during our analysis for this paper as her approach to classroom norms surfaced as a unique and notable practice in her classroom. The purpose of the interview was to understand more about how the classroom norms were established and the value she placed on them for the success of her students.

2.2 | Approach to Analysis

The conceptual framework element of a commitment to a collective enterprise, alongside Ms. Seaborn's explicit list of norms, served as an initial set of deductive codes (c.f., Table 1). We used our prior definitions of inviting and actualizing a commitment to a collective enterprise (Alzen et al. 2023) to identify instances where Ms. Seaborn used norms to encourage, or invite, students to work together to make sense of science ideas and when she and the students actually took up, or actualized, the joint work. We did not set out to compare norms to collective enterprise in this analysis but rather to investigate norms as a way to support collective enterprise. We also used the idea of risk-taking as a subcode under collective enterprise as prior research indicates that some actions teachers may encourage under the umbrella of a commitment to a collective enterprise require students to take intellectual risks (Beghetto 2009; Cetin et al. 2014; Clarke 2015). Although feelings of uncertainty are a common result of risk-taking (Chen 2022; Starrett et al. 2024), we did not code for uncertainty as it was a connection made after analysis. Because we did not anticipate the need to ask students directly about uncertainty, it was difficult to track students' internal feelings about it in our data.

In our first pass at the data, two members of the team identified excerpts where any of the primary codes were evident. This occurred when the teacher explicitly encouraged classroom norms or directed students to consider classroom norms via a classroom artifact (i.e., poster on the wall, copy students had in notebooks). In classroom video, these were moments when students had opportunities to work collaboratively toward a common goal and to maintain or enact common and explicit norms agreed upon in class. For all data sources from Ms. Seaborn, the two researchers tagged moments for further analysis where they judged her reflections or instructional moves to be consistent with any of these key ideas. They also tagged data excerpts for further analysis when students named or recognized classroom experiences that aligned with these concepts. During this process, they also looked for evidence of disconfirming or inconsistent evidence, but there were no such instances in the data set.

The two coders conducted this first pass at the data independently and then met to confirm codes. Following the first round of coding, these two individuals iteratively took additional passes at the data for more focused coding, wrote analytic memos to summarize observed patterns, and met with different subgroups of the full team to discuss the data and themes that emerged from the process (Saldaña 2021). Additionally, full team meetings occurred with all authors approximately every 2 months to discuss specific data excerpts and/or analytic memos to further develop ideas as a team. This iterative process helped us to continue developing our conjectures regarding the potential relationship between classroom norms, intellectual risk-taking, and actualized collective enterprise around building science ideas. To finally construct the case, we identified the data that most clearly answered our research question by showing ways that the classroom norms promoted intellectual risk-taking and collaborative knowledge building. This occurred through summarizing across student interview data, selecting an illustrative extended episode to demonstrate deeper evidence drawn from the student interviews about collective enterprise and norms, as well as chunking data across classroom episodes to gain an understanding of how the evidence about norms and collective enterprise were broadly evident across our time in Ms. Seaborn's class and not only evident in an isolated episode.

3 | Results

We begin our presentation of results with a summary of how the students spoke about their experiences in class. These data helped us understand the extent to which students recognized and appreciated the classroom culture Ms. Seaborn worked to establish, and if there was obvious recognition of class being a place with an emphasis on a collective enterprise around building science ideas. Following, we present an extended

TABLE 1 | Coding guide.

Primary codes	Subcodes	Definition	Example
Collective enterprise		"collaborative idea production" (Damşa et al. 2010, p. 152)	"This is our whole class [idea]. Everyone's participation and ideas are valued" (SP22 observation transcript)
	Invite	Teacher defines and encourages the necessary behaviors/tasks for engaging in group work.	"Are we listening? How do we show that we're listening?" (SP 22 observation transcript)
	Actualize	Teacher and students accept and take up the joint work together	T: "Can anybody build on this idea that she started?" S: "I think she's saying..." (SP23 observation transcript)
	Risk-taking	Acts such as sharing untested or first-draft ideas, asking questions, and challenging majority viewpoints. Actions that could produce undesirable outcomes including being dismissed or ridiculed, receiving negative criticism, or being perceived as having a lack of understanding	"What do we think the job of the respiratory system might be? [...] I want you guys to take a risk." (SP22 observation transcript)
Norms (see Figures 2 and 3)		"classroom level cognitive and social structures operationalised through the collective expectations of the teacher and students about what counts as appropriate activities and interactions" (Makar et al. 2015, p. 1108) --explicit and common expectations	"What does respectful mean? What does it sound like/What does it look like? What should we expect from each other?" (Follow-up interview)
	Respect/Safety	"Our classroom is a safe place to share" (Norms artifact)	"I hear ideas [...] Who is willing to take a risk?" (SP22 observation transcript)
	Equitable	"Everyone's participation and ideas are valuable" (Norms artifact)	"I need to see you using hand signals today. And that we share for those who are shy" (SP22 observation transcript)
	Commitment to our community	"We learn together" (Norms artifact)	"Going back to [student's] question, when he said..." (SP23 observation transcript)
	Figure things out together	"We learn as a team" (Norms artifact)	"The kids need to see each other as integral parts of the community within the classroom. They need to help each other and build on each other's ideas" (Reflection SP22)

classroom episode and related data that served as a primary source of understanding how norms supported intellectual risk-taking and a commitment to a collective enterprise as seen in whole-group discussion. Although we do not have the student data to substantiate claims about students' feelings of uncertainty, we also present these data as evidence to suggest that the classroom norms potentially enabled a student to share his uncertainty and the group to navigate that uncertainty together. We then present data from curricular and classroom artifacts and teacher interviews to explore how Ms. Seaborn initially organized classroom norms and expectations in ways that may have created the conditions for the extended episode illustrating intellectual risk-taking to occur. Finally, we present data that show the ways that Ms. Seaborn facilitated maintenance of classroom norms and expectations and the ways that maintenance may afford opportunities for and encourage students to take risks and commit to a collective enterprise of building science ideas.

3.1 | Students' Characterization of Ms. Seaborn's Classroom

The student interviews were designed for students to describe their experiences in science class generally rather than specifically asking them about any key ideas in this study. Despite this, many of our codes surfaced as key themes in how students described their experiences in class. Ms. Seaborn's students

regularly made individual comments about their ownership over learning. Class was "student-led" (FA21) and "the class" figured things out for themselves (SP22; FA22), while Ms. Seaborn was there to "support" them (FA21). Students also indicated that they worked together. "Everyone talks" (FA22; SP23), and they "paraphrase and build [on one another's ideas...] so people can understand" (SP23). One student went as far as to say "I think mostly everything in the classroom is built off of each other's ideas. I think we really advanced and like building on each other and listening to each other a lot" (SP23). The students also named some specific tools in class to assist with this cooperative knowledge building. They stated there were classroom norms to "help other students out" (FA22), the class created a "social contract" to support their learning (SP23), and students were expected to set goals and help one another reach them (SP23). In addition, students named whole-group discussion as "a good time to be confused" (FA22), a space to "build on others' [ideas]" (SP22), and a time to potentially "change your way of thinking" (FA21) because of the opportunities to compare thoughts and ask questions of one another.

Students mentioned that they described their experiences in class in these ways because in Ms. Seaborn's class "there are no wrong answers, [and] it makes people want to share more" (SP23). Further, students said there were norms that reassured them that "whatever [they] say matters" (SP23) and these commitments are publicly displayed: "we all wrote our names on [the social contract], and I love that because that can remind us of what we should do and rather than her reminding us, we just look [at] the wall and see it" (FA22). Both the classroom norms and the social contract were on the classroom walls, something multiple students pointed to during interviews. Students also had individual copies of the classroom norms pasted in the front of their science notebooks and our team observed reference to these norms during our classroom visits.

The themes of working together to figure things out and regular contributions from all students were consistent across the student interviews. They referred to class as a safe place to share, where it was okay to disagree and be unsure. Additionally, the students named that classroom norms and expectations were a key part of their classroom culture, they had joint ownership over them, and they referred to them during class. The student data provided some evidence that their experiences in Ms. Seaborn's class aligned with reform-oriented goals for science. In addition, it was a class where the social risk of contributing ideas out loud was encouraged, because the tentative, and possibly wrong, ideas of everyone were valued by the teacher and by peers. Further work is needed to understand more about the student experience from their perspective, but we next move on to a classroom episode in which this potentially risky behavior was observed.

3.2 | Intellectual Risk-Taking in Whole Group Discussion

In FA22, our research team visited Ms. Seaborn's classroom as they studied a unit regarding atomic models, chemical reactions, and conservation of mass. In this unit, students explored the question "How can we make something new that was not there before?" (Novak and Novak 2022). The day before, students determined that new substances might be formed when the particles of previous substances rearrange to form new combinations of particles. Students also developed investigation ideas to determine what substances make up the gas bubbles that appear when a bath bomb is placed in water. This excerpt was chosen for deeper analysis because of the observed risk-taking and actualized collective enterprise across multiple students. This data excerpt starts as Ms. Seaborn shared some confusion with her students.

> Ms. Seaborn: *I kind of left here [yesterday] and I was like, "I'm kind of confused."*
>
> *[Students use hand gestures to show agreement]*
>
> Ms. Seaborn: *You got confused? I was confused too. I was like, "Hey, I don't really know why we're testing water."*
>
> *[Students use hand gestures to show agreement]*
>
> Ms. Seaborn: *Yeah. Charlie is like, "That's what I asked you guys yesterday!" Go ahead [Say it, Charlie].*
>
> Charlie: *I was wondering why we were testing water because we found out that the new substance wasn't water. It was a new substance. [Charlie's voice starts to get harder to hear].*
>
> Donna: *Can you say that louder, [Charlie]?*
>
> *[Ms. Seaborn brings the class microphone, and Charlie explains again in a louder voice]*
>
> Charlie: *We know that the new substance isn't citric acid, baking soda, or water, so I'm wondering why we're testing water and not testing the bath bomb.*

Ms. Seaborn surfaced a moment in which the students were grappling with an area of uncertainty. She used this both as a connection to the previous lesson and to start off the day's discussion. In response, Charlie used hand gestures to contribute to the conversation and then Ms. Seaborn encouraged him to share what he was unsure about. He not only shared his confusion, but another student asked a question to ensure that she could understand what her peer was saying. In reflecting on this moment, Ms. Seaborn named that she worked to have a classroom community in which students felt comfortable being unsure:

> *This is really great because all of a sudden they're like, "Oh [...] what the heck are we doing?" And [Charlie...] felt included, and like his idea is being heard, and, like what he said was important, and then valued by the community. You know? He didn't feel alone or isolated. I purposefully planned that because I heard him saying that [he was confused] the day before and I was like,*

"How am I going to bridge this gap?" Because I know that they don't get it. It's not just him. I'm happy that he stepped up and said, "I don't understand," which means that I have a safe community that he can do that.

Knowing that her students were not fully understanding the purpose of the investigation, Ms. Seaborn leveraged her students' willingness to be unsure to guide discussion. Charlie sharing his confusion showed that he felt safe to take a risk amongst his classmates. Later in the same class, Charlie revealed this willingness to engage in intellectual risk-taking again:

Charlie: *[This investigation is] helping us figure out what's happening to the particles because all the particles are going to do the same thing. So, if they all do the same thing [trails off]. I'm trying to figure out how to say it. Can I, like, have some time?*

Ms. Seaborn: *Yeah. Leo, you had a question about what [Charlie's] saying. Maybe if you ask the question, you can help move our thinking forward.*

Leo [to Charlie]: *What did you mean by do all the particles do the same thing? [...]*

Charlie: *Oh because when the citric acid goes into the water, it makes the bubbles. So, every time that those particles go into water, it's going to make the bubbles. So, they're all going to do the same thing.*

Ms. Seaborn: *Can anybody paraphrase what Charlie is saying? Craig?*

Craig: *I think he's trying to say that if we mix the citric acid, baking soda, and water, it's going to make a fizz, no matter what. They both, citric acid and baking soda, are both properties. [Leo, who sits next to Craig, makes "I agree" hand gesture.]*

Ms. Seaborn*: Donna, what's the question you have?*

Donna: *[Craig is] saying that citric acid and baking soda are both properties, but those are substances. They're not properties.*

Craig: *You're right.*

Ms. Seaborn: *Do you want to rephrase?*

Craig: *Oh yeah. They uh...yeah...[Looks at Leo] Say it, Leo.*

Leo: *I think [Craig] means, like the fizz, how they interact with the water, those are properties.*

Craig: *Yeah. Yeah. Exactly.*

In this segment of the data, we saw a commitment to a collective enterprise, risk-taking, and enactment of multiple classroom norms. Charlie shared his incomplete thought, and Ms. Seaborn encouraged Leo to ask a question to help Charlie process. Then, Ms. Seaborn asked for a student to paraphrase Charlie's thought so that multiple students participated in making sense of ideas. Students were respectful when they asked questions and made comments about others' ideas, even when correcting vocabulary use (i.e., properties and substances). Next, another student asked a question.

Mandy: *But how would the particles interact with the water?*

Ms. Seaborn: *Do we know that answer yet?*

Multiple voices: *No*

Ms. Seaborn: *So how would doing these [points at investigation ideas] help us figure that out, Donna? [...]*

Donna: *If the water particles have the same effect as the bath bomb particles. Like if they have the same properties as the bath bomb particles, then it can help us eliminate more potential gasses and it can also help us understand like a deeper meaning of how the particles interact.*

Shortly after this, Ms. Seaborn directed the students back to the ideas for investigation they generated the previous day and asked them to explain what they were trying to discover from these investigations. She then circled back to Charlie, who started this segment of class with his partial explanation of the properties of citric acid and water.

Ms. Seaborn: *What might happen if we run electricity through [water], Charlie?*

Charlie: *Maybe it causes a different reaction. Maybe it's not the same substance then?*

[...]

Josh: *Like if we can see what actually happens when particles combine, it will prove what we were thinking [motions toward models built the previous day].*

Ms. Seaborn: *So is it important to test the water?*

Multiple students: *Yes!*

At the beginning of this excerpt, Charlie was comfortable sharing an idea that was not fully formed and then asking for more time to think. Ms. Seaborn then encouraged Leo to contribute to help Charlie with his thinking. From there, various students engaged with one another's ideas about the purpose of testing the water. This segment included multiple students taking risks. Some in sharing incomplete thoughts and others in asking questions of a peer's thinking. From here, the group

went on to conduct the investigations that were already planned for the day, but only after multiple of them contributed to a conversation explaining the reasons behind these particular investigations.

Charlie participated in a group student interview shortly after this classroom episode occurred. When asked about his contributions to the discussion, Charlie responded: "I just want to make sure that, like, I'm on the same page as everyone else and not to be left behind." He later went on to say that in Ms. Seaborn's class, "If you're confused, it's never for long, really, because eventually [...] we're gonna have a big talk about [our ideas]." Charlie expressed his desire to be learning alongside his peers and the comfort he felt with being unsure of his ideas for a short time because he trusted that the class processes would eventually provide him an opportunity to ask questions and gain better understanding from his peers. When Ms. Seaborn reflected on this same classroom interaction, she commented: "I've been moving towards [this] for a long time or trying to get my class to get here. Where I can just stand back, and the kids start to ask the questions of each other. They're stealing my moves."

Ms. Seaborn's students actively engaged in risk-taking and collaborative learning by sharing incomplete thoughts, addressing moments of confusion, asking one another questions, and using hand signals to communicate their thinking. These practices helped the group share ideas about the chemical reactions they observed when bath bombs were placed in water. To uncover how such interactions became a regular part of the classroom, we first examine classroom artifacts and interviews with Ms. Seaborn to understand how she established norms at the start of the year. We then analyze data collected over multiple days to investigate how Ms. Seaborn's consistent reinforcement of these norms fostered an environment in which students were comfortable engaging in classroom discussion in potentially risky ways.

3.3 | Initial Classroom Norms

Ms. Seaborn and her students used the terms "social contract" and "norms" for their explicitly agreed upon expectations for class, so both sets of agreements fall under our working definition of classroom norms. Figure 1 shows an example of a social contract. Since these were established during the first few weeks of school, our research team did not have the opportunity to observe their creation. Instead, we interviewed Ms. Seaborn to learn about her approach to creating them.

> *The social contract is a set of behaviors when you walk into my classroom. I don't have a list of rules that the students follow because this is really student-driven and a place where students feel socially accepted—that they can make an impact. Me going top down and giving them the rules is not going to create that safe space for them. [...] Within the first week of school, we're creating our social contract. It's a contract between themselves and myself. [...] I tell my students, you have been in school for 8 years. You know how to behave in the classroom, and I'm putting my full trust in you that you are going to develop these rules that we [should have] so that our classroom remains safe and a place that you want to be.*
>
> (Follow-Up Interview)

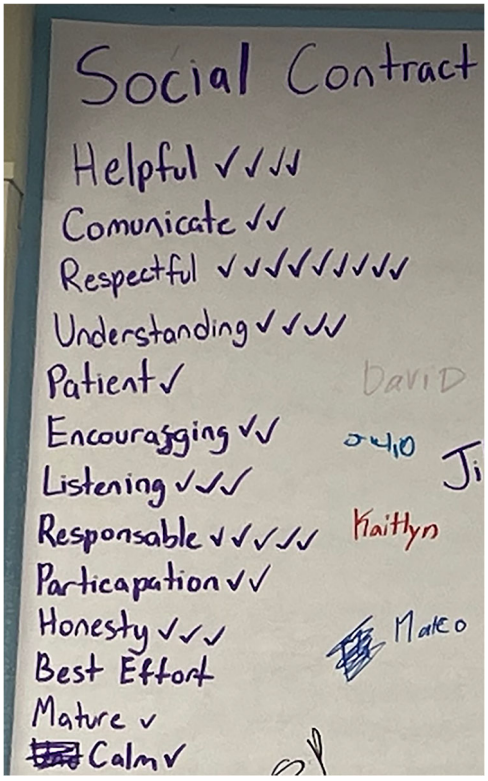

FIGURE 1 | Example of Ms. Seaborn's classroom social contract.

Ms. Seaborn goes on to explain that she facilitates the creation of the social contract by posing four questions to the students:

1. How do you want to be treated by me, the leader?
2. How do you want to treat each other?
3. How do I [the leader] want to be treated by you?
4. How do we treat each other when there's conflict?

Ms. Seaborn stated that students were directed to answer these questions with one-word answers or short phrases, and she guided the students to talk explicitly about what they exactly meant by each term. When students wished to repeat an answer, they added a checkmark to the list. At the end of the activity, everyone signed the document, and Ms. Seaborn made it clear that this was a living document that could be pulled down and revised. However, Ms. Seaborn reported that in her 16 years of using this tool, she has only pulled a contract down once to go back and revisit the terms. Ms. Seaborn also noted that though she facilitates the conversation, she does not have any input on what goes on the contract. Of their own accord, the students named several key elements that support reform-oriented science classrooms such as communicate, listening, respectful, and participation.

While the social contract is something apart from the curriculum that Ms. Seaborn established for each of her classes, the

Co-develop norms for consensus-building discussion

1. **Respectful**: Our classroom is a safe space to share
2. **Equitable**: Everyone's participation and ideas are valuable
3. **Committed to our community**: We learn together
4. **Moving our science thinking forward**: We work to figure things out

FIGURE 2 | Professional development slide regarding establishing classroom norms.

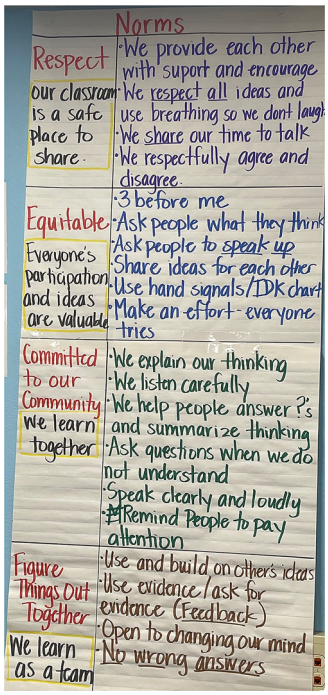

FIGURE 3 | Example of Ms. Seaborn's classroom norms.

expectations she refers to as norms are derived from her curricular materials. Figure 2 shows the slide from the professional development Ms. Seaborn attended with our team that illustrates classroom norms as suggested in the curriculum, and Figure 3 shows an example of norms directly from Ms. Seaborn's classroom.

Ms. Seaborn reported adopting the norm categories directly from the curriculum and described how the related specific actions were co-created by the students:

> *At the beginning of the school year, I give my students an [open-ended] experience [...] And it's through working together that they start to see things, and I'm noticing them too. [...] I give them some feedback at the end. "You know, you guys are just learning how to work with these group members. Something I noticed as I was watching you is some of you participate, and some of you don't. What are reasons that you or somebody else might not participate?" And they generate a whole list of ideas. [...] And we go through each idea of what students said, and the question then becomes "How do we help these students?"*
>
> (Follow-Up Interview)

Ms. Seaborn went on to explain that students generated ideas for how to help students to participate more (right column of Figure 3), and she organized the ideas into the categories from the curriculum (left column of Figure 3).

Though we rely mostly on follow-up interview data to understand the establishment of these norms, we also have data before enactment regarding Ms. Seaborn's emphasis on norms. In a reflection after the initial professional development meeting, Ms. Seaborn stated she wanted "to take a step back and have students do most of the work and feel like they're able to take risks" in her classroom in the coming year. However, to do this, Ms. Seaborn said "a lot of practices and routines need to be used to build that community to take risks." In talking about planning for the year, Ms. Seaborn emphasized she would tell students, "You need to be a risk taker. You need to help others. You need to invite others into the conversation." This early reflection, along with the social contract and classroom norms jointly established by class participants provided evidence of some of the elements of classroom culture Ms. Seaborn identified as important at the beginning of the school year. She acknowledged that risk-taking was necessary for the type of classroom environment she hoped to establish and that norms were a way she could support her students in taking those risks. We hypothesize it is both Ms. Seaborn's facilitation of student involvement in working toward goals aligned with these norms and her regular evocation of these norms that created a classroom culture that was safe for students to take risks and facilitated opportunities for the group to engage in a collective enterprise around making sense of science ideas.

3.4 | Norms Maintenance

Something notable about norms in Ms. Seaborn's class was the active role accountability to the norms took during class on a regular basis. The norms were not on a dusty poster in the corner of the classroom serving as a long-forgotten artifact of discussions during the first week of school. Instead, Ms. Seaborn's commitment to actively maintaining classroom norms and expectations were consistently evident during all 4 weeks of classroom observation conducted over the course of this study. While this manifested in various ways and to varying degrees across class sessions, two consistent practices were evident: goal setting and discussion facilitation anchored to norms. In each of these practices, Ms. Seaborn emphasized the need for risk-taking as necessary for their class learning.

3.4.1 | Individual Goals

Ms. Seaborn dedicated a significant amount of class time to students setting and tracking their progress toward weekly goals related to the class norms. This practice started at the beginning of the year to help students acclimate to the classroom culture and set expectations for collaborative idea production in class. Ms. Seaborn acknowledged that her students would come in with different ideas about what it meant to be in science class together and would thus have different goals.

We start off the school year by setting individual goals because each of my students are in different places, and I have to respect that right learning as a journey. Some people, their road is bumpy and turney and other people are on the autobahn, and that's awesome [...] But how do we get everybody to that same point?

(Follow-Up Interview)

Ms. Seaborn emphasized this individuality in goal setting throughout the year and stressed that goal setting be an ongoing reflective process. For example, during our SP22 observations, she asked students to look over their written reflections about their previous week's goals and asked them to use those reflections to inform their new goals:

When you write your goal this time, you're going to use what you said you needed to work on to help you write your goal. [...] Maybe I'm like, "Hey, I'm really not understanding, so I really need to focus on asking questions. When I write my goal here, it should be about asking questions."

(SP22 Transcript)

This individual goal setting took a good part of a class period every week. When asked about this use of time, Ms. Seaborn reported that she did it because it really helped with getting students to engage with one another during class. She indicated some previous difficulty she tried to address through the norm-related goals:

It was like pulling teeth to get students to talk. And it's still not easy. [...] But there's a lot more participation [now...] The kids are really starting to use the hand signals because it's part of their goals. [...] You have to keep coming back to the norms. You just have to. You can say it one time and then it's good for a little while, but if you keep revisiting it, it's more powerful."

(FA21 Daily Debrief Interview)

In this excerpt, Ms. Seaborn explained that revisiting the norms was important and that by revisiting norms through goal setting, she was able to see a difference in her students' engagement with one another. In this class, students could use hand signals to indicate if they agreed, disagreed, had a question, would like to add, or could paraphrase. This is one of the specific actions related to the classroom norm of being equitable (c.f. Figure 3). Ms. Seaborn saw change in her students' behavior as a result of goal setting. She regularly used this activity to stress that everyone's participation and ideas were valuable and needed for the class to move forward in making sense of their ideas together.

Another important aspect of goal setting was regularly reminding students to think about their goals after they were set. Two days after the goal setting described above, Ms. Seaborn had students think about their goals as they prepared for a full class discussion:

Look back at your goal for this week. Read it over to yourself. [...] And I want you to think to yourself, what are you going to do to show your classmates and me that you're working on your goal [during our discussion]? How will we see that you're doing what you said you were going to do? Tell your shoulder partner. How are you going to show that you're working on your goal? [students talk with partners] Alright, now that you've shared your ideas with your shoulder partner, shoulder partner, your job is to hold this person accountable. If they're not doing what they said they're going to do, you need to remind them like, hey, you should be working to meet your goal, because right now you're not.

(SP22 Observation Transcript)

Although students set these goals for themselves on an individual basis, the community was a part of accountability to meeting those goals. Students were asked to take risks in making their goals public, and shoulder partners and table groups were often tasked with the risky behavior of holding peers accountable to their goals. Ms. Seaborn's emphasis on setting individual goals while also supporting others in helping them reach their goals is one way by which she used norms on a regular basis to encourage students to participate both in developing science ideas as well as working together toward gaining science knowledge together as a group.

3.4.2 | Classroom Goals

About halfway through the year, in addition to personal goals, Ms. Seaborn had the class set whole group goals for specific class discussions called "science circles." The purpose of these discussions was for everyone to physically come together in a circle to share ideas and hear one another. It was in the context of science circles that students in the group interviews made comments such as "The science circle really helps a lot because that's where we all share ideas and get new ideas from other people, and I feel like a lot of people contribute to the science circle" (SP23 Student Interviews).

During one of our visits, we observed how the classroom level goals worked as the class prepared for a science circle where they were planning to discuss what they agreed upon and where there were still questions about a particular topic. Ms. Seaborn opened the conversation by projecting the student survey results from Figure 4 and stating the following:

The last time that we came to a science circle, you guys filled out a survey. Do you guys remember filling out that survey? [yeah] And here's some data from your survey. Let's just start with 'What do you notice?'

(SP23 Observation Transcript)

One student commented: "a majority of students are either tracking the speaker or raising their hands to share ideas. Yay!" Another student noted "We are doing a lot better than we did

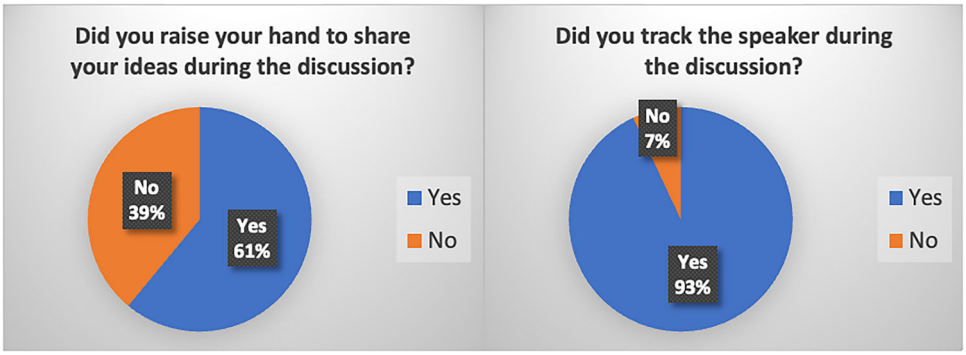

FIGURE 4 | Results presented to students from previous class science circle survey.

last time" (SP23 Observation Transcript). After a bit more reflective conversation, Ms. Seaborn commented:

> *We are doing really good at tracking the speaker. Does that need to be one of our goals then today? [No] No. I mean, we're going to keep it in the back of our mind. Like, we still need to do it, but it doesn't have to be our goal today. [...] So what are some things that we still really need to work on? And something that might help us is to go back to our norms, which are on the inside front cover of our notebook, and we're going to choose three, not all of them. What are the top three things that our class really needs to focus on today? [...] Turn and talk with your group members. What are some things we really need to focus on?*
>
> (SP23 Observation Transcript)

The students discussed in small groups and voiced ideas such as "encourage students who still aren't sharing," "we can help people ask questions and or summarize thinking," "everyone should raise their hands at least once," "encourage [others] to raise their hand if they didn't," and "use evidence maybe because sometimes we don't use evidence" (SP23 Observation Transcript). Ultimately, the class decided that their three goals for the day's science circle would be to keep track of who raised their hands and encourage those who did not, once they had spoken to wait for at least three others to speak before they contribute again (e.g., 'three before me'), and help people answer their questions and summarize their thinking.

During the following whole-group discussion, Ms. Seaborn reminded students about their goals with comments such as "Can somebody help [student] out? Remember, one of our goals is to summarize thinking" and "[Student] is saying a lot, but he's saying something really important. [...] Is there somebody who can summarize for the rest of the group?" (SP23 Observation Transcript). At the close of the conversation, Ms. Seaborn mentioned the goals once more, "I'm noticing that people are like reflecting. They're like, 'Hey, my group met their goals.' That's awesome" (SP23 Observation Transcript).

The classroom goals added another layer of accountability to and maintenance of the class norms for discussion. Students not only set their own goals and helped their group members track and meet their individual goals but also worked together with the entire class to be better at maintaining their norms as a whole. Additionally, we saw evidence of collective support for intellectual risk-taking in the class-level goals through encouraging everyone to share, ask questions, and summarize thinking. These goals at varying levels kept the norms central to the regular class activities rather than a forgotten artifact on the wall from the first weeks of school. Instead, they were an integral part of guiding class participation.

3.4.3 | Class Discussion Facilitation Anchored to Norms

In addition to individual- and class-level goals, Ms. Seaborn regularly facilitated reminders of the norms through the ways she engaged in classroom discussion. Across lessons, we saw Ms. Seaborn work toward equitable contributions to class discussion with comments such as "What do you guys think about that?" (SP22; SP23 Observation Transcript) and "I need to hear from somebody I've not yet heard from" (SP23 Observation Transcript). Ms. Seaborn also reminded students about their class commitments outside of formal goal setting:

> *As a class, we're also going to be working on [being] equitable. Everyone's participation and ideas are valued [...] We really need to make sure that we're using three before me. Those of us who speak a lot, we ask people to speak up and encourage them to share. We use hand signals. I'm going to be holding you guys accountable.*
>
> (SP22 Observation Transcript)

Later in the same class period, some students were still hesitant to participate in conversation. Rather than allowing for a few students to dominate the discussion, Ms. Seaborn stopped the class:

> *I'm gonna pause this. Because I think that people have really important ideas here. But when they're unsure about their ideas. What do you notice people are doing? [shy] They're becoming shy. But if we look back at our norms, let's look at our norms. Everybody look over there. One thing we said is that we had to make an effort. Is it OK to be wrong in this class? [yes] Will we figure things out, though, if people don't take risks? We need people to do what? [Take risks] take risks. So Abbey, we're going to*

ask you to take a risk. Abbey, what were you adding to our conversation?

(SP22 Observation Transcript)

Students in this class were regularly reminded of the expectation to participate and that sharing their ideas was important. It was also regularly acknowledged that some of their contributions might be difficult because the students were shy, or their contributions might require risk-taking. Ms. Seaborn's recognition of this risk-taking and explicit encouragement for the environment to be a safe place to take risks made it clear to everyone in the room the kinds of contributions that were being solicited, supported, and encouraged.

Additionally, Ms. Seaborn modeled how to be committed to the community. She encouraged this norm through comments such as "Can I just pause you for a second so that everybody's looking at the same thing you are? Can you tell us what you're looking at?" (SP22 Observation Transcript), "Turn and tell them, not me" (SP23 Observation Transcript), "Wait. Look at [student] because he's saying something really important right now" (SP23 Observation Transcript), and "What does he mean when he says that?" (SP23 Observation Transcript).

Another practice she enacted at the end of whole group discussions was to have students identify something someone else said that helped them: "Let's thank some people. What are some things that we heard others say that helped move our science thinking forward?" (SP23 Observation Transcript). This sort of conversation helped make it apparent why it might be worth engaging in potentially risky behavior in class. Students could see and recognize where sharing ideas or questioning one another assisted individual peers or helped move their class thinking forward as a whole. Finally, the idea that the class worked to figure things out together was obvious in Ms. Seaborn's discussion facilitation through explicit use of talk moves (Michaels and O'Connor 2012) such as "Can anybody build on this idea?" (SP22; SP23 Observation Transcript), "Is there anything anybody else can add to that idea?" (SP22; SP23 Observation Transcript), "Do we have evidence for that yet?" (SP23 Observation Transcript), and "Say more" (SP22; SP23 Observation Transcript). The use of talk moves to support norms was another way that Ms. Seaborn supported students in taking intellectual risks. She helped students to share, expand their own thinking; listen to one another; and think together with others. Her regular use of these talk moves also helped students to know what to expect if they shared ideas.

4 | Discussion and Implications

We constructed this case study to further explore our prior work's conjectures regarding how teachers can support reform-oriented science classrooms (Alzen et al. 2024). In particular, we investigated the specific ways that this teacher used classroom norms to support students in intellectual risk-taking for the purpose of making sense of science ideas together. Reform-oriented science classrooms require shifts in the ways that teachers and students participate in learning science and the expectations for classroom contributions they have for the members of the classroom community (Alzen et al. 2024; Carrier 2013; Manz et al. 2020; Miller et al. 2018). Because those shifts ask many students to participate in ways that may seem unfamiliar (e.g., sharing incomplete thoughts or questioning prominent ideas), teachers striving for reform-oriented science carry the burden of convincing students that engaging in these unfamiliar ways is safe, worthwhile, and valuable for their learning experiences. This means that teachers need to envision and enact a support structure for student interaction and participation.

Establishing and cultivating a classroom culture that supports students in engaging in a collective enterprise of making sense of science ideas together is a significant way teachers can shape their students' experiences (Cavanagh and Waugh 2004), and one key element of building such culture is establishing norms and expectations (Makar et al. 2015; Wright et al. 2018) that support and encourage intellectual risk-taking (Beghetto 2009; Cetin et al. 2014; Clarke 2015). However, simply having norms does not mean that a particular classroom culture will exist (Chang and Song 2016), nor does it guarantee that students will buy into any particular classroom roles such as engaging in collaborative and intellectually risky work. Maintenance of the norms to cultivate classroom culture over time is important for norms to be an effective lever for establishing a specific classroom culture (Wright et al. 2018), particularly when the desired culture requires students to participate in ways that may feel risky in part because sharing a sense of confusion or uncertainty is not the norm in school (Lemos 2002; Manz and Suárez 2018). While these assertions may seem self-evident, a continuing challenge in our field is creating and sharing careful accounts of these reforms in practice. It is easy to say that developing and maintaining a classroom culture that encourages and supports risk-taking is important, but it is much harder to know exactly how to do that. The case presented above demonstrates some of the key features and replicable aspects of this classroom that allowed it to operate as a community engaged in reform-oriented science practices.

The evidence from our case study analysis suggests several key actions performed by Ms. Seaborn and taken up by her students that may have contributed to minimizing the risk students felt while engaging with knowledge construction. First, the ways in which Ms. Seaborn engaged her students in co-construction and enactment of norms or expectations seemed to promote student buy-in. Both Ms. Seaborn and her students attested to the ways their norms were developed together, and we observed joint ownership over using them in class. Everyone in the class had access to the co-developed expectations and everyone was expected to participate in holding one another accountable to them within the classroom space. The fact that students brought up the norms both generally in practice and as specific actions they took in class revealed their uptake of that element of classroom culture and shows how norms may be a specific tool teachers can use to encourage the kinds of classroom participation hoped for in science education reform (Beghetto 2009; Mitton and Murray-Orr 2021).

Second, these norms and expectations were clearly and regularly emphasized both verbally and through keeping them accessible. Not only were they posted on the wall, but both teacher and students reported referring to that public display as

a means to remind the class about behavioral goals and ways of engaging with one another. Each student also had a copy at the front of their notebooks and the teacher prompted them to reference that on a regular basis. This regular revisiting of agreed upon expectations reflects what prior research says about continually supporting the culture needed for high levels of student engagement (Cobb et al. 2009; Makar et al. 2015; Yackel and Cobb 1996).

Thirdly, there were specific and regular classroom activities such as individual and classroom-level goal setting that served to emphasize the importance of attending to the classroom community and the key function of the norms and expectations served in maintaining that community. Not only were the individual goals set on a weekly basis and whole class goals determined for every science circle, but there were reminders about, accountability to, and reflection on evidence that students gathered around their progress towards meeting goals. Ms. Seaborn's emphasis on working toward the types of classroom participation required by the classroom norms helped students to know that what might be perceived as risky behavior and different from prior school experiences was actually what was valued by their teacher. As others have previously argued, these classroom activities showed how norms can be actively used by teachers to encourage particular classroom culture (Makar et al. 2015; Wright et al. 2018).

Finally, the norms and expectations encouraged intellectual risk-taking and centered around sharing ideas and working together to build science knowledge. Individuals agreed that everyone's ideas were needed to further their developing science ideas, so the class was seen as a place worth taking risks to move their thinking forward. Students mentioned needing to hear ideas from others and sought out ways to encourage more individuals to participate because they saw it as valuable for developing their knowledge. Students even saw their confusion and uncertainty as contributing to the collective knowledge building and the class was seen as a place worth taking risks to move their thinking forward. They also trusted that moments of uncertainty would eventually be resolved as the class continued to wrestle with ideas together. The role of uncertainty in science and how to embrace it has become a focus of scholarship in science education over the last decade (Chen et al. 2024; Manz and Suárez 2018; Schwarz et al. 2022; Starrett et al. 2024). These scholars have called out how challenging it can be to manage and promote the importance of uncertainty. As Chen et al. (2024) note:

> *Pedagogically engaging students in productive struggle with scientific uncertainty requires careful theoretical examination of how scientific uncertainties should be defined and invited in the classroom, and how to support students to navigate those uncertainties responsively, aligning with students' learning trajectories.*
>
> (p. 1101)

Ms. Seaborn's actions and the students' commitment to the classroom culture provide an example of how the students' uncertainty can be positioned in a positive light in the collective knowledge-building work in the science classroom, mitigating the risk students may feel when they are unclear or confused. Following Ms. Seaborn's mention of unsettled ideas, Charlie's repeated willingness to share his confusion, incomplete thoughts, and questions invited opportunities for more students to engage in the discussion. As a result, even though the class determined a list of investigation ideas the previous day, Charlie's risk-taking enabled deeper discussion of the purpose of the investigations from a disciplinary standpoint. In other words, the students could better explain the science concepts they were exploring through their investigations because a peer shared his confusion. In retrospect, Charlie mentioned that he was comfortable being uncertain because he felt confident the class would ultimately come together and make sense of their different ideas. In this instance, it was actually his willingness to share his questions that paved the way for an opportunity for deeper understanding. Although we have some evidence of Charlie's thoughts regarding this interaction, more work is needed to further understand the positive role norms can play in navigating the uncertainty needed for collective knowledge-building work. Research that investigates student feelings of uncertainty and the mechanisms that influence those feelings and willingness to act despite those feelings can shed even more light on specific ways teachers can support reform-oriented science classrooms.

In addition to inquiry regarding norms, uncertainty, and risk in science classrooms, we also identified another important area for future research. Our work initially set out to understand broadly the ways that norms could support a reform-oriented classroom culture, but we did not anticipate the prominence and importance of goal setting in Ms. Seaborn's classroom. A more careful study of the role goal setting can play in establishing and maintaining classroom culture should be the focus of future research, but here we make some connections between what we saw in Ms. Seaborn's classroom and the goal setting literature.

Goal setting theory suggests that individual, specific, and challenging goals can yield higher group performance and that whole group goals significantly affect group performance (Kleingeld et al. 2011; Locke and Latham 2006). Ms. Seaborn encouraged students to set specific goals for themselves directly tied to the classroom norms as opposed to more generic goals such as “participate more” or “put in your best effort.” Additionally, she encouraged students to set potentially difficult goals when she asked them to set goals related to intellectually risky behavior such as asking questions when they were unsure or sharing when they felt shy. This seemed to be a key way that Ms. Seaborn was able to support students in intellectual risk-taking and participating in a collective enterprise of building science knowledge together. She indicated that before using individual goals related to classroom norms, “it was like pulling teeth to get students to talk. And it's still not easy [...] But there's a lot more participation [now]” (FA21 Daily Debrief Interview). Goal-setting theory suggests that Ms. Seaborn's commitment to having her students set difficult and specific goals was likely a motivating factor in the change she observed in her students. This is because such goals motivate action and provide direction for where efforts should be focused (Kramer et al. 2013). Rather than thinking that they needed to participate more, students were primed to think about the specific actions they needed to

take to meet the goals they set for themselves about *how* they would participate. By asking her students to set goals related to the classroom norms, Ms. Seaborn directed her students to identify how they would direct their efforts toward intellectual risk-taking and building knowledge together.

Ms. Seaborn also held students accountable to their goals regularly across and within individual class meetings, and she marshalled the students to hold one another accountable to their individual and group goals as well. By setting goals, individuals have a motivation to direct their attention and mobilize their efforts in particular ways (Kleingeld et al. 2011). However, that motivation is moderated by the feedback individuals receive and their commitments to their goals (Locke and Latham 2006). Future work should consider the ways goals, both related to classroom norms as well as other aspects of classroom participation, may be used as an effective tool for maintaining particular classroom cultures.

This paper focused on one element of classroom culture, norms, and identified specific tools used to uphold those norms in an effort to develop and sustain a reform-oriented science classroom. There are many other elements that make up culture that are worthy of study such as student relationships and networks, participant structures, and physical and non-verbal cues. Future work could investigate how these and other elements of classroom culture can work in tandem or individually to support students to work as collectively as they further their science knowledge. Another implication of this study is for curriculum developers and their consideration of educative or supportive materials within curriculum design to support teachers in maintaining the characteristics of classroom environments conducive to reform-oriented science teaching and learning such as the norms studied here. For example, instructional materials could suggest concrete activities such as classroom level goals for whole-class discussion that could be implemented throughout the school year to provide teachers with ideas about how to engage in the ongoing work of creating and working with norms in ways that support a collective enterprise of learning science ideas.

5 | Conclusion

Science education reformers call for teachers to shift more responsibility for knowledge-building work to their students and that a clear aim is for students to incorporate one another's ideas as they develop knowledge together. Ample evidence documents the characteristics of classrooms in which students have embraced such classroom participation, but more work is needed to sufficiently support more teachers in successfully making these shifts. Such student engagement can be seen as risky, and students must be convinced that these risk-taking behaviors are worthy efforts. The current study shows how bringing students into the development and implementation of classroom norms designed for the purpose of supporting students to collaboratively build science knowledge is a specific act teachers can perform to make strides toward mitigating the risk that students perceive in such environments. As more teachers enact practices such as establishing and maintaining such classroom norms, increasing numbers of students will benefit from science education that emphasizes their authentic and purposeful learning experiences.

Author Contributions

Jessica L. Alzen is the primary author, responsible for full text of article and analysis. Jason Y. Buell is the secondary author, responsible for some writing, analysis, and primary reviewer. Kelsey Edwards is the data analyst, responsible for managing analysis work. Chris D. Griesemer, Yang Zhang, Cynthia Passmore, William R. Penuel, and Brian J. Reiser are responsible for theory building, idea development, group analysis, revision, and editing.

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Ethics Statement

This study was approved by the IRB of Northwestern University.

Conflicts of Interest

The authors declare no conflicts of interests.

Data Availability Statement

Due to IRB restrictions, data are not publicly available for this study.

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