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The role of equitable classroom cultures for supporting interest in science

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Abstract

Supporting student interest in science is critical for broadening participation in the field because interest, even more than achievement, is associated with pursuing future science education and careers. In this study, we explore the conjecture that equitable classroom cultures can support interest in science. Specifically, we examine the idea that science classroom cultures that equitably reflect collective enterprise (where students engage collaboratively in scientific sensemaking) and care (where students believe that they are valued and respected members of the classroom community) support students, particularly those from historically marginalized populations, to develop interest in science. The study is part of a field test of a new middle school science curriculum called OpenSciEd. Data consist of survey responses from 847 students across 34 teachers located in nine states. Our analysis employed mixed-effects models to accommodate the nested structure of the data. We found that classrooms vary substantially in the degree to which they reflect collective enterprise and care, indicating that classroom culture is a

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perceptible and consequential feature of the shared classroom environment. Student background did not predict reports of collective enterprise or care, providing evidence that classrooms in our sample were equitable along these dimensions. Critically, collective enterprise and care are both strongly associated with student-reported interest in science. These findings underscore the importance of attending to classroom culture and the relational aspects of science learning as we seek to expand interest in science, particularly for students from historically marginalized populations.

KEYWORDS

caring environments, classroom culture, collective enterprise, science, science interest

1 | INTRODUCTION

For the past many decades, broadening participation in science and other STEM fields has been of key national importance. Although elementary school students typically express a strong interest in and curiosity about science, that interest declines sharply in the middle grades, particularly for girls and racially minoritized youth (see Potvin & Hasni, 2014a, 2014b, for a review). Scholars now understand that this declining interest is not due to a lack of ability, but rather to sociocultural features of schooling and of science as a discipline that continue to exclude girls and students of color (Ceci et al., 2009; Su & Rounds, 2015). Cultural aspects of schooling and of science in particular hinder students from developing the interest in science and identification as scientists that are essential to pursuing future education and careers in these fields (Calabrese Barton & Tan, 2020; Carlone & Johnson, 2007).

Interest in science is of critical importance because it supports better science learning and promotes persistence in science and other STEM fields (i.e., technology, engineering, and math). Interest is particularly central to learning for students from low-income and minority backgrounds who have historically been underrepresented in the sciences (Marin & Bang, 2015). Students who are interested in a topic learn better because their interest supports greater focus and attention within the learning process (Deci et al., 1991; Deci & Ryan, 1994; Koestner & Losier, 2002; Reeve, 2002; Schiefele et al., 1992). Interest is also a key determinant of both science identity development and pursuing future education and careers in STEM (Kang et al., 2019; Kang & Keinonen, 2017; Maltese & Cooper, 2017; Nugent et al., 2015). Research has found that interest, above and beyond achievement, influences who chooses to pursue careers in STEM (Tai et al., 2006).

This article explores the conjecture that classroom culture is one factor that influences student interest in science. Classroom culture is essential in shaping the science learning experiences that students encounter because it determines the nature of relationships and interactions within the classroom, as well as the roles, tasks, and participation structures available to students (Black et al., 2004; Supovitz & Turner, 2000). In science classrooms, the culture

reflects how science itself is presented to students and shapes the opportunities that students have to engage in scientific sensemaking (Krist et al., 2016; Tal & Kedmi, 2006). Classroom cultures can be more or less equitable, depending on the extent to which they value and legitimize the identities, knowledge, and experiences of all students in the room, particularly those from backgrounds that have historically been marginalized within school science (Aikenhead & Jegede, 1999). Equitable classroom cultures serve to expand and improve science opportunities for students who are often marginalized in society and in school, particularly students from historically marginalized racial/ethnic and/or gender subgroups (Carlone & Johnson, 2007; Penuel et al., 2023).

Our research explores the relationship between features of equitable classroom cultures and student interest in science at scale. We examine the extent to which classrooms vary in key elements of classroom culture. And we explore the relationship between that classroom-level variation and reported student interest in science across a large number of middle-grade science classrooms. This large-scale study enables us to examine how much of the variation in experiences of classroom culture and interest in science are particular to the student or the classroom, and where relationships between the two are consistent across individuals and contexts. This study aims to provide evidence from a broad swath of classrooms, operating within varied school, district, and state contexts, about the relationship between specific features of equitable classroom cultures and student interest development in science.

The context for our study is the field test of OpenSciEd middle school curriculum units, a set of full open access instructional materials designed to align with the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) and designed from the outset to support more equitable participation in science learning. Data come from 847 students in 34 teachers' classrooms located in nine different states. With this study, we aim to contribute to the field's understanding of equitable classroom cultures that support interest development in science for all students, especially girls and youth from historically minoritized racial/ethnic communities.

2 | CONCEPTUAL FRAMEWORK

The focus of our work is to explore the classroom-level conditions that support equitable interest development in science. Here, we draw on existing theories of interest and interest development, as well as literature about equitable classroom cultures and science learning, to theorize about how and why particular science classroom features might promote science interest for all students, particularly those from populations that have been historically marginalized based on race/ethnicity and/or gender (e.g., girls, non-binary students, and students of color). We consider these groups to be "historically marginalized" or "nondominant" in that the cultures of schooling and of science as a discipline have commonly excluded the people, voices, and cultural ways of knowing of these communities through institutional structures and practices that reify dominant narratives of what counts as, and who excels at, science (Bang et al., 2017; N. S. Nasir et al., 2006). As learning is a deeply cultural process (Gutiérrez & Rogoff, 2003), connecting to and building on students' own cultural knowledge and ways of knowing directly supports both learning and disciplinary identification (Bell et al., 2017). However, possibilities for identification are limited for nondominant groups, due to traditional alignments between school and science with Western, White, and patriarchal forms of knowing (N. I. Nasir, 2011; Warren et al., 2001; Warren & Rosebery, 2011). Our conceptual framework theorizes about how science classrooms might expand the possibilities for cultural connection in service of interest development in science.

2.1 | The nature of interest and its role in science persistence

Scholarship on interest tells us that interest in a particular object is not an innate characteristic. Instead, culture, context, and relationships all play a role in shaping interest, both as a state of enjoyment or curiosity and as a more enduring state of being (Azevedo, 2011; Barron, 2006; Hidi & Renninger, 2006). Interest consists of multiple components that interact dynamically with one another and with the environment to shape the strength of one's interest in a given topic at a given time and over an extended period of time. Here we explore the unique characteristics of interest to lay the foundation for understanding how science classroom cultures connect with student interest in science.

2.1.1 | Characteristics and components of interest

The person–object theory of interest defines interest as the relation between a person and the object of interest and argues that interest consists of three central characteristics: cognitive, emotional, and values-related (Krapp, 2007). The *cognitive* aspect of interest refers to a person's readiness to acquire new knowledge in relation to the topic of interest. People who are interested in a particular subject are not content with their existing knowledge or abilities; rather, they have a desire to expand and apply their knowledge and skills. The *emotional* aspect of interest refers to positive emotions such as enjoyment connected with an area or activity of interest. These emotional aspects of interest drive motivation (Wigfield & Eccles, 2000); that is, when people feel positive emotions associated with a subject or activity, they develop intrinsic motivation to continue. Finally, the *values-related* characteristic of interest refers to the fact that objects of interest will hold personal significance for the individual, and the goals of the interest area will be compatible with the goals and values of the individual. This values-related valence can also refer to the idea that engaging with a particular object of interest aligns with an individual's own motives and goals (Krapp, 2007). We propose that by "plugging into" each of these components of interest, science classroom cultures can support student interest in science.

2.1.2 | The development of individual interest

The four-phase model of interest development describes how interest develops from context-dependent situational interest to more enduring individual interest (Hidi & Renninger, 2006). Capturing situational interest is an important first step in building sustained interest; while supporting the transition to sustained individual interest is important because this form of interest has especially strong benefits for learning and persistence within a particular field (Koestner & Losier, 2002). External factors, notably the learning environment and instructional tasks, influence both the triggering of situational interest and the development of more sustained individual interest. Learning environments that provide "meaningful and personally involving activities"—such as problem-based learning and cooperative group-work—can help build situational interest (Hidi & Renninger, 2006; Mitchell, 1993; Renninger et al., 2004; Riegle-Crumb et al., 2019). In turn, learning environments and tasks that provide both challenge and opportunity lend support for emerging individual interest (Pressick-Kilborn & Walker, 2002; Renninger, 2000; Renninger & Shumar, 2002).

2.1.3 | Interest in science and science classrooms

The cognitive, emotional, and values-related aspects of interest have been examined in several studies focused on science. Students are more likely to develop interest in science when they perceive that science connects with their values. Scholars have found that promoting the perceived utility value of science by encouraging students to make connections between science and their lives and futures boosts interest for students (Basu & Barton, 2007; Hulleman & Harackiewicz, 2009). Cognitively and emotionally, scholars have found that curiosity and enjoyment related to particular practices of scientific inquiry contribute to the development of interest in science (Ainley & Ainley, 2011; Luce & Hsi, 2015). For example, students may experience a thrill when, having made a prediction about the outcome of an experiment, they then conduct the experiment and find their prediction substantiated. These emotions connected with the doing of science (as opposed to feelings about science as a topic) can help to drive interest in science.

Many scholars have also documented the importance of perceived recognition for interest development in science (Carlone & Johnson, 2007; Kalender et al., 2019). Perceived recognition refers to the feeling that influential others see you as competent and capable in science. This component of interest development is particularly important in science classrooms, where students are accustomed to receiving judgments from teachers (and peers) about their abilities as science students—judgments that play an outsized role in shaping students' beliefs about their own place within the field of science. These unique characteristics of interest development in science point to the aspects of the classroom culture that matter for establishing the fertile ground that can support students to develop interest in science.

2.1.4 | The importance of interest for persistence in science

Interest plays a key role in students' persistence in science and other STEM fields. Interest in science is often sparked early (middle school or before) and through school-based factors and experiences (Maltese & Tai, 2010). Females in particular point to the role of teachers and other mentors in sparking their early interest in STEM fields (Maltese et al., 2014; Maltese & Cooper, 2017). This inchoate interest in science has the potential to impact students' course-taking and career choices, even above and beyond their math and science achievement (Tai et al., 2006). Ainley and Ainley (2011) found that interest in science was highly correlated with students' future participation in science-related activities and careers. Maltese and Cooper (2017) similarly found that interest was the most common factor for persisting in STEM over time. Researchers have found that there is no singular pathway leading toward successful STEM majors, in terms of the timing or manner of triggered interest (Maltese et al., 2014; Maltese & Cooper, 2017). Nonetheless, the consistent role of interest in STEM persistence, combined with the known influence of school on triggering (or dampening) science interest, points to the critical importance of attending to the classroom-based factors that can effectively support student interest in science, particularly for students from historically marginalized populations.

2.2 | Equitable science classroom cultures and interest

Classroom culture refers to an amalgamation of factors within the classroom that together create the environment that students experience and that shape their opportunities for learning

and growth (Cavanaugh & Waugh, 2004). Classroom culture encapsulates the nature of the relationships and interactions within the classroom, including norms for speaking and working together (Kang & Furtak, 2021; Kang & Nation, 2023; Krist, 2020; Supovitz & Turner, 2000), as well as the roles and participation structures that are available to and expected of students (Black et al., 2004). Classroom culture reflects how knowledge-building happens within the classroom and who participates, including the kinds of thinking and sensemaking that are valued, and what students are held accountable for knowing (Calabrese Barton, Tan, & Birmingham, 2020; Calabrese Barton, Tan, & McDaniel, 2020). The culture is also evident in what it means to be considered "smart" or "successful" within the classroom (Carlone et al., 2011).

In science classrooms specifically, the culture reflects how science itself is presented to and experienced by students, with attendant implications for whether and how students have opportunities to connect with the discipline of science (Tal & Kedmi, 2006). The culture establishes how people treat each other within that space, how they talk to and with one another, what role they have in building knowledge, how they handle uncertainty and mistakes, etc. Classrooms can vary substantially in each of these areas, for example, in some classrooms teachers may be in charge of presenting established knowledge to students, whereas in other classrooms students may be expected to take part in collective knowledge-building efforts.

We conjecture that equitable classroom cultures can broaden interest in science by expanding who has opportunities to connect with the cognitive, emotional, and values-related aspects of interest development in science. Such classrooms offer environments where all students have opportunities to engage in scientific sensemaking and thus experience epistemic emotions connected with science practice, including curiosity, confusion, and enjoyment. These experiences are likely to be particularly consequential for students from historically marginalized communities whose cultural ways of knowing are not typically reflected within traditional school and science cultures (Bang et al., 2017; Bell et al., 2017). These epistemic emotions are important because they drive interest. Such classrooms can also expand students' understanding of what science is, how it happens, who can participate, and toward what ends (Bang et al., 2012; Carlone et al., 2011)—thus expanding the potential for students to see their own values reflected in the scientific enterprise.

2.2.1 | The role of equitable classroom cultures in science

Recognizing the sociocultural nature of science and science learning points to the importance of understanding how students affiliate with and/or become alienated from science, via their experiences within their science classroom communities (Carlone & Johnson, 2007; Lave & Wenger, 1991). The classroom culture and the nature of the relationships and interactions within classrooms shape student experiences and opportunities for interest development (Renninger & Hidi, 2002; Sansone & Smith, 2000). As we elaborate below, equitable classroom cultures can serve to attenuate the effects of systemic inequities, expand the boundaries of sanctioned disciplinary participation, and broaden opportunities for students to connect with science. These openings are essential for students to find the emotional, cognitive, and value-related connections to science that can drive interest in the discipline.

Classrooms are borderlands where multiple sociocultural contexts collide (Gutiérrez et al., 1999) and traditional classroom cultures—emerging from racialized and gendered contexts and structures of education, science, and society—often align more closely with the lives of students from dominant communities than with those of students from nondominant

communities (N. S. Nasir & Vakil, 2017). These deeply ingrained alignments implicitly communicate the value of some knowledge, experiences, and ways of knowing over others (Bang et al., 2012; Bell et al., 2017). Through didactic teacher-centered instruction and a focus on individual accomplishment over joint knowledge-building, many science classroom cultures also implicitly communicate that science is a "finished body of knowledge" and that the good science students are the ones who always have the right answer to the teacher's questions (Schwab, 1982). These narrowly construed ideas about what science is and how to do science alienate many students, particularly those from racially and ethnically minoritized communities (Bang et al., 2012; Bell et al., 2017). By expanding ideas about what science is and who can meaningfully participate, equitable classroom cultures can lay the foundation for a broader range of students to connect with science (Bang et al., 2017).

Concomitantly, a single classroom environment can function very differently for different students or groups of students. Although a group of students may occupy the same classroom space with the same teacher and peers, they do not necessarily experience the classroom culture in the same way (Carlone & Johnson, 2007; Schweig & Martínez, 2021). Indeed, a single classroom can contain multiple cultures in one, reflecting differential expectations for subgroups of students, different sets of rules, expectations, and pedagogical strategies (Babad, 1993; Brophy & Good, 1974; as cited in Schweig & Martínez, 2021). Here, we discuss two features of classroom cultures—collective enterprise and care—and describe how they can manifest within contemporary science classrooms and what it means for them to be cultivated equitably.

2.2.2 | Connecting collective enterprise with interest in science

Collective enterprise refers to "collaborative idea production" wherein students and the teacher work together to build and advance students' understanding of scientific concepts (Alzen et al., 2020; Scardamalia & Bereiter, 1991). This endeavor entails collaboratively sharing and exploring ideas, respectfully critiquing one another's ideas, and engaging in collective sensemaking to reach conclusions and build understanding (Reiser et al., 2017). Practices where students engage together in making sense of phenomena further underscore that students have a role to play in science, and moreover that science is a collective, collaborative endeavor.

Fostering equitable collective enterprise means establishing norms and expectations of inclusion wherein students have (and perceive themselves to have) equitable opportunities to contribute to group discussion and sensemaking. In these spaces, teachers support purposeful sensemaking where, through students' exercise of their own agency with others, they advance the class' understanding of phenomena they are studying (Alzen et al., 2020). To create such environments, teachers and students must recognize the diverse ways that students can contribute to the group and invite and accept contributions reflecting varied ways of knowing and forms of experience (Clarke et al., 2016; Patterson, 2019).

We conjecture that in classrooms where students engage in collective enterprise, students build the emotional, cognitive, and values-related foundations for developing interest in science. Although the existing literature does not provide evidence for this relationship directly, the literature does provide a basis for our conjecture: Classroom cultures and norms that encourage student initiative and problem-posing—as in classrooms that enable collective enterprise—serve to build intellectual and emotional ownership over the work and can promote science interest (Azevedo, 2018). Related, engaging in scientific sensemaking can expand how

students understand their role in science (Carlone et al., 2011), thus potentially creating more opportunities for students to build cognitive and emotional connections to the discipline. Moreover, by definition, engaging in collective enterprise enables students to see science as a communal effort geared toward solving scientific problems (Scardamalia & Bereiter, 1991). In this sense, engaging in collective enterprise may enable students to connect science with the values-driven component of interest. Connecting to communal values has been found to be particularly relevant for girls: Research has shown that girls place high value on communal goals, but that they often perceive science as being antithetical to such goals (Ceci & Williams, 2011; Diekman et al., 2010, 2011; Kang et al., 2019). As such, collective enterprise can convey to students that science is a collaborative and communal endeavor, which may in turn support interest development in science.

2.2.3 | Connecting caring environments with interest in science

Caring environments are those in which teachers and students attend to one another's needs and welfare (Noddings, 2012). In science, caring environments demonstrate fidelity to persons, that is, the commitment of students to the growth and well-being of others, grounded in caring relationships (Krist & Suárez, 2018). As students engage with scientific practices, *epistemic caring* is particularly important; this type of caring entails positioning students as knowledgeable and their ideas as valuable, treating one another's ideas with respect, working to understand one another, and collectively building a shared understanding of the phenomenon at hand (Krist & Suarez). Teachers can also demonstrate caring in science by letting students know that they empathize with the struggle to understand new ideas (Jaber et al., 2022). Such environments foster the trust that students need to feel comfortable being vulnerable—an essential feature of grappling with the uncertainty that is inherent to scientific inquiry and sensemaking (Krist, 2020).

Within caring environments concerned explicitly with equity, teachers and students notice harms and inequities within interactions, particularly how others may be silenced or made to feel invisible in classrooms (Patterson, 2019) and work to build a culture that affirms racially minoritized students and elevates their voices (Carlone et al., 2011). Such environments also promote *critical caring*, which conjoins culturally relevant curricula and identity-affirming pedagogies with high-quality relationships and high expectations for student success (Antrop-González & De Jesús, 2006).

We propose that caring environments also have the potential to nurture student interest in science. Classrooms built around relationships, and around science activities that further students' social priorities, greatly support the development of sustained interest in science (Basu & Barton, 2007). Further, classroom cultures oriented toward caring and collective well-being lay a foundation of trust and safety that enable students to take on the risks and vulnerability required to engage in scientific practices and sensemaking together (Carlone et al., 2021). A willingness to share ideas vulnerably is critical for participating in and getting a "feeling" for science, which in turn support further engagement and emerging interest in the discipline (Jaber & Hammer, 2016a, 2016b). Strong and caring relationships support feelings of enjoyment associated with the subject, which supports the emotional dimension of interest. Finally, showing care by conveying to students that they are knowledgeable, and their ideas are valuable, likely provides students with the recognition that in turn supports interest development.

3 | THE CURRENT STUDY

The current study aims to identify specific aspects of equitable classroom cultures that support student interest in science at scale. The study is part of a larger implementation field test of the OpenSciEd middle school curriculum. The field test and associated research took place from 2018 through 2021 in science classrooms across the country. This section provides details about the OpenSciEd curriculum and about the participant sample, data collection, and research methods for this study.

3.1 | The intervention: About OpenSciEd

The teachers in the study were implementing field test versions of 6–8-week science units aligned to the NGSS (NGSS Lead States, 2013). Each unit follows a storyline that begins with an anchoring phenomenon and develops around student questions and investigations about that phenomenon (Reiser et al., 2021). These storyline units are a form of project-based learning in the sense that students figure out key ideas through engaging in science and engineering practices to explain phenomena and design solutions to problems (Penuel et al., 2022). As detailed below, an integrated set of teaching routines, educative supports embedded in materials (Davis & Krajcik, 2005), and professional learning helps teachers to foster an equitable culture that supports collective enterprise and caring.

3.1.1 | Support for collective enterprise

A central feature of collective enterprise is that students work together to figure out science by sharing and exploring ideas together (Scardamalia & Bereiter, 1991). A related component of collective enterprise is having agency to generate questions, identify ways to investigate those questions and determine a course of action (Alzen et al., 2020). The OpenSciEd curricular materials and a core set of routines support students in collaborating to figure out a phenomenon or solve a problem; students do not figure things out in isolation, and they do not follow prescribed investigation procedures. For instance, within the Anchoring Phenomenon Routine, students collaboratively explore a puzzling phenomenon or problem, develop initial models to explain what is happening, and identify related experiences and phenomena that could help them explain the phenomenon or problem. Students also generate and prioritize questions that the class agrees are important to pursue over the course of the unit, and they identify potential investigations that could help them answer their questions. The sensemaking and knowledge-building processes also happen collaboratively: throughout each unit, students engage in tasks that require them to synthesize information gathered across small groups (e.g., using the Jigsaw technique); to compare and evaluate explanatory models of peers; and to come to consensus on models of phenomena that best reflect evidence students have encountered and developed as part of the unit.

The OpenSciEd professional learning provides additional resources and opportunities to prepare teachers to cultivate classroom cultures where students work together to figure out key science ideas. A key role for teachers in fostering collective enterprise is to facilitate student contributions in ways that enable and advance collective sensemaking (Clarke et al., 2016; Patterson, 2019). To support this facilitator role, OpenSciEd teachers receive discussion

planning tools, which direct them to establish goals for discussion, plan for how they will encourage students to work with one another's ideas, and decide on how to synthesize agreements and disagreements among students. Further, these tools differentiate purposes for discussion, including for generating initial ideas, putting pieces of knowledge together, and coming to consensus on scientific understandings. An important feature of professional learning is engaging educators as if they were students participating in knowledge-building together in "student hat" (Lowell & McNeill, 2020), a strategy intended to help teachers gain a feeling for what it feels like to be a student inside a classroom where knowledge is being constructed together, and not simply given by the teacher or text.

3.1.2 | Support for caring

Support for caring is embodied in a set of common agreements for OpenSciEd classrooms that are introduced and modeled in professional learning and supported within curriculum activities (Table 1). These agreements are intended to support equitable participation by fostering a community in which people are committed to one another's learning and well-being, both recognized components of care (Krist & Suárez, 2018; Noddings, 2012). The agreements acknowledge that the cultures that typically emerge in science classrooms often align with dominant cultures; to disrupt that pattern, teachers and students must intentionally co-construct classroom norms that help all students feel respected and valued (Antrop-González & De Jesús, 2006; Patterson, 2019). The agreements fall into four broad categories, each of which integrates a dimension of care: respectful, equitable, committed to our community, and moving our science thinking forward. For example, under the category of respectful, specific norms encourage mutual support and debate where ideas are critiqued but not persons. Under the category of equitable, norms encourage active seeking out of voices and appreciation of diversity. Together, these agreements are intended to cultivate spaces where students experience the care required to support the vulnerability and uncertainty required to engage in figuring out science.

3.2 | Research methods

This study focused on examining the relationships between features of equitable classroom cultures and students' interest in science. Specifically, we sought to answer the following research questions:

- To what extent do classrooms vary in the degree to which they reflect cultures of collective enterprise and caring?
  - How do student reports of classroom culture vary by race/ethnicity or by gender subgroups?
- To what extent do classrooms vary in the extent to which students express science interest?
  - How do student reports of interest vary by race/ethnicity or by gender subgroups?
- How do collective enterprise and caring relate to students' reported interest in science?
  - Is the relationship between classroom culture and interest moderated by student race/ethnicity or by gender?

To address these questions, we first investigated the degree of variability both between and within classrooms with respect to reports of classroom culture (i.e., collective enterprise, care)

TABLE 1 New science classroom agreements reflecting support for care.

Norms	Agreements	Talk moves to support norms
Respectful *Our classroom is a safe space to share.*	• We provide each other with support and encouragement. • We share our time to talk. We do this by giving others time to think and share. • We critique the *ideas* we are working with, but not the *people* we are working with.	• "Daniel, that's a great idea. How do you think we could investigate it?" • Give time to think using wait time, turn and talk, or during individual writing time, such as Stop and Jot. • "Why do you disagree with Juan's idea?" rather than "Why do you disagree with Juan?"
Equitable *Everyone's participation and ideas are valuable.*	• We monitor our own time spent talking. • We encourage others' voices who we have not heard from yet. • We recognize and value that people think, share, and represent their ideas in different ways.	• "I'd like to hear from someone who hasn't yet gotten a chance to talk." • "How did we do today in our discussion making space to hear from everyone?" • "The way Shayna described ____ really helped me think about it in a different way."
Committed to our community *We learn together.*	• We come prepared to work toward a common goal. • We share our own thinking to help us all learn. • We listen carefully and ask questions to help us understand everyone's ideas. • We speak clearly and loud enough so everyone can hear.	• "Who can paraphrase what Selma just said?" • "What did your partner say?" • "What questions do you have for Shereen about her idea?" • "I think I heard what you said, but can you say it again to make sure everyone heard?"
Moving our science thinking forward *We work together to figure things out.*	• We use and build on other's ideas. • We use evidence to support our ideas, ask for evidence from others, and suggest ways to get additional evidence. • We are open to changing our minds. • We challenge ourselves to think in new ways.	• "Why do you think that? What's your evidence?" • "Do you agree or disagree with what Juan said? Why?" • "Who can add onto Jerome's' idea?" • "Did you see something represented in someone else's work that changes how you are thinking about ____?"

Source: Table reproduced from New Science Middle School Curriculum, Teacher Handbook Version 4.0.

and interest. To be equitable, we would expect that students with a variety of different identities (e.g., race/ethnicity, gender) would report experiencing similar, high levels of collective enterprise and care (as well as interest) within the same classroom. In turn, we seek to understand the relationship between those features of the classroom culture and student interest in science.

3.2.1 | Participant sample

Ten states participated in the OpenSciEd field test: California, Iowa, Louisiana, Massachusetts, Michigan, New Jersey, New Mexico, Oklahoma, Rhode Island, and Washington state. The project leads within each state recruited teachers for the study and made decisions around compensation structures, which consequently differed by state. The data for this study come from

TABLE 2 Demographics and descriptive statistics: Collective enterprise, care, and interest.

	n (%)	Enterprise mean (SD)	Care mean (SD)	Interest mean (SD)
Race/ethnicity				
African American or Black	57 (6.88)	4.87 (0.89)	5.32 (0.91)	3.84 (1.01)
Native American	22 (2.65)	4.87 (0.72)	5.21 (0.77)	3.94 (0.76)
Asian or Asian American	30 (3.62)	4.65 (0.72)	5.28 (0.77)	3.73 (0.81)
Latinx or Hispanic	143 (17.25)	4.81 (0.85)	5.18 (0.92)	3.74 (0.98)
Multiple	127 (15.32)	4.75 (1.14)	5.08 (1.16)	3.87 (1.09)
White	450 (54.28)	4.96 (0.79)	5.25 (0.83)	3.90 (0.84)
Gender				
Boy	376 (46.48)	4.88 (0.91)	5.27 (0.87)	3.90 (0.91)
Girl	424 (52.41)	4.94 (0.72)	5.23 (0.82)	3.88 (0.86)
Non-binary	9 (1.11)	4.41 (0.66)	4.54 (1.25)	3.43 (1.10)

survey responses gathered in Spring 2021 from 847 middle-grade science students in 34 teachers' classrooms across nine different states (Washington did not participate that semester). On average, each teacher had 24.9 students (SD = 19.2) respond to the student end-of-unit survey. During the Spring 2021 semester, each classroom worked with one OpenSciEd unit: sixth graders studied Cells; seventh graders studied Earth's resources; and eighth graders studied Natural Selection. Students identified with a range of racial/ethnic communities and gender identities are shown in Table 2. We had fewer than five students identifying as Native Hawaiian/Pacific Islander in our sample ($n = 3$), and so we removed these observations from the data.

3.2.2 | Data source and measures

The data source for this study was a student survey, which was a composite measure created by the research team based on the literature, including existing validated scales for middle schoolers. Students completed the survey at the end of their OpenSciEd unit in the Spring of 2021. The survey included questions about students' background and home language, their experience of the classroom culture within their science class, and their interest and identification with science.

The research team created scales for collective enterprise, care, and interest (among others that do not form part of the analysis for this study). The collective enterprise scale drew on literature describing collective enterprise as an endeavor where students share and critique ideas to collaboratively build and advance their understanding (Alzen et al., 2020; Scardamalia & Bereiter, 1991). The care scale drew on ideas from (Krist & Suárez, 2018) arguing that care in science learning environments entails (a) respecting students in part by respecting their ideas and (b) a commitment to everyone's well-being and growth. The interest scale drew conceptually from the Expectancy Value Cost Scale of Interest (EVC; Kosovich et al., 2015) and the Students' Perceived Utility Value Scale (Harackiewicz et al., 2012). Specifically, we adapted items

that aligned conceptually with values-related component of person–object theory and created additional items to align with the emotional and cognitive components. The resulting interest scale thus aligns with Krapp's person–object theory of interest, addressing all three components of interest.

We conducted a post hoc exploratory factor analysis of the student end-of-unit survey items relevant to our study to provide information about how items cluster along the three target constructs: collective enterprise, care, and interest. Initial factor analysis of the 19 items theorized to comprise these constructs resulted in three distinct factors based on the eigenvalues, of which three factors had values above the threshold of 1 (see Tables A1–A5 in Appendix).

We then focused on the 13 items we theorized to make up collective enterprise and care and the six items that are part of our interest scale. For the collective enterprise and care items, the eigenvalues showed two distinct factors. We used promax oblique rotation (as opposed to orthogonal rotation) because we had theoretical reasons to believe that the two factors (constructs) would be correlated. Subsequent analysis confirmed this relationship, showing a correlation coefficient of 0.64 between the two factors. Eleven of the 13 items loaded onto one or the other of our two factors with a loading of at least 0.3 or above; one item loaded onto both factors; and one item did not load onto either factor. The item that loaded onto both factors read, *We work together with our teacher to make decisions in our class*. This item has a strong conceptual alignment with the collective enterprise construct, and so we included it in that scale. The item that did not load onto either factor was a reverse-scored item that read, *The teacher makes all the decisions about what we do in class*. The reverse nature of the item may have caused confusion; and students may have had different interpretations of what it means for the teacher to make "all the decisions" about the class. Consequently, we decided not to include this item as part of either scale. A separate factor analysis of the six interest items showed these items to be unidimensional, with one eigenvalue above the threshold value of 1, and with all items strongly loading onto one single factor. The final scales were structured as follows:

Collective enterprise

The scale measuring collective enterprise contained six items. Questions included statements such as: "*We work together to come up with explanations for the phenomena we are studying*," "*We are expected to connect our ideas to the ideas of other students*," "*We incorporate everyone's ideas into our explanations of phenomena*," and "*My questions/interests/wonderings influence what we do in class*." The item response options were (1) strongly disagree, (2) moderately disagree, (3) slightly disagree, (4) slightly agree, (5) moderately agree, and (6) strongly agree. The Cronbach's alpha for our scale was 0.84, suggesting strong reliability of the scale. The overall mean score was 4.88, ranging across student subgroups from 4.41 to 4.96, out of 6 max.

Care

The scale measuring care contained five items. These items included statements such as, "*The teacher shows respect for everyone's ideas*," "*The teacher gives help to those students who need it"* and "*All students are treated fairly*." Again, students responded on a six-point agree/disagree Likert scale. The Cronbach's alpha for this scale was 0.91, also suggesting strong reliability of the scale. The overall mean score was 5.21, ranging across student subgroups from 4.54 to 5.32, out of 6 max.

Interest

The scale measuring interest contained six items, aligned with Krapp's person–object theory of interest (Table 3). Two of the items reflect emotional characteristics of interest, such as a sense

TABLE 3 OpenSciEd interest measure and alignment to person–object theory of interest.

Interest scale item	Component of interest
I enjoy science activities	Emotional characteristic
I look forward to my science class	Emotional characteristic
I am interested in the things I learn in science class	Cognitive characteristic
I think making an effort in science class is worthwhile	Values-related
I think science will help me even when I am not in school	Values-related
I think it is important to do well on science assignments	Values-related

of enjoyment. One item addressed the cognitive component of interest, asking about the extent to which students are interested in the content of the class. Three items addressed the values-related component of interest, thinking about whether science is helpful and worthwhile. The item prompt asked students how much each statement "describes you," and the answer choices were: (1) Not at all like me; (2) a little bit like me; (3) somewhat like me; (4) quite a bit like me; (5) exactly like me. The Cronbach's alpha for this scale was 0.90, suggesting strong reliability across items. The overall mean score was 3.86, ranging across student subgroups from 3.43 to 3.94, out of 5 max.

3.2.3 | Analytic approach

In the first phase of the analysis, we examined the aspects of classroom culture—specifically collective enterprise and care—as the outcome variables, using hierarchical linear models with students nested within classrooms. With these models, we examined both the degree of classroom-level variation in aspects of classroom culture and the extent to which participating OpenSciEd classrooms were equitable with respect to student experiences of the classroom culture. Specifically, to understand classroom variability in aspects of classroom culture, we fit unconditional models with care and collective enterprise as the dependent variables. We examined the classroom- and student-level variance components for these models, and the intraclass correlations, to understand the proportion of variation that exists at the classroom and student levels in the data. We also tested the null hypothesis that the classroom-level variation in collective enterprise and care was equal to zero, using an exact restricted likelihood ratio test to test the significance of the random effects.

To interrogate the degree of equity within these classrooms, we fit additional models that included indicator variables for student gender and race/ethnicity as fixed effects. We used Black students as our reference group, to decenter the White experience as the standard for comparison. We used emmeans (Lenth, 2022) to test the significance of the differences for all the applicable pairwise contrasts. Equitable classrooms would be ones in which the characteristics of student identity, such as gender or race/ethnicity, are not associated with students' experience of care and collective enterprise in classroom cultures.

In the second phase of analysis, we modeled reported student interest as the dependent variable, again using hierarchical linear models and nesting students within classrooms. We examined the proportion of classroom- and student-level variation using an unconditional model of interest, with students nested within classrooms. We tested the null hypothesis that classroom-level variation in science interest was equal to zero, again using an exact restricted likelihood

ratio test to test the significance of the random effects. To interrogate the degree to which students of different race/ethnicities and students of different genders report similar or different levels of interest, we added students' self-identified race/ethnicity and gender as fixed effects within the model, again nesting students within classrooms. We used emmeans to test all the relevant pairwise comparisons between student gender and race/ethnicity subgroups. We also investigated differences by grade level/unit in terms of student interest in science. Here, we used sixth graders (studying the cells unit) as the reference group; the other groups were seventh graders (studying Earth's resources) and eighth graders (studying natural selection).

Finally, we created two separate models to investigate relationships between classroom culture and interest: in one model, we used student-reported collective enterprise as our focal covariate, and in another we used student-reported care as the focal covariate. We included interactions between care with gender and race/ethnicity respectively, and between collective enterprise with gender and race/ethnicity respectively, to understand whether the relationship between culture and interest varies by student background characteristics. We retained grade level/unit as a covariate for interest. Our final Level 1 and Level 2 models for science interest with care as the covariate of interest were as follows:

*Composite model with care * gender interaction*:

$$\begin{aligned}\text{INTEREST}_{ij} = {} & \beta_0 + \beta_1(\text{CARE})_{ij} + \beta_2(\text{RACE})_{ij} + \beta_3(\text{GENDER})_{ij} + \beta_4(\text{UNIT})_j \\ & + \beta_5\left(\text{CARE}_{ij} * \text{GENDER}_{ij}\right) + u_{0j} + r_{ij}.\end{aligned}$$

*Composite model with care * race interaction*:

$$\begin{aligned}\text{INTEREST}_{ij} = {} & \beta_0 + \beta_1(\text{CARE})_{ij} + \beta_2(\text{RACE})_{ij} + \beta_3(\text{GENDER})_{ij} + \beta_4(\text{UNIT})_j \\ & + \beta_5\left(\text{CARE}_{ij} * \text{RACE}_{ij}\right) + u_{0j} + r_{ij}.\end{aligned}$$

Wherein:

i = Level-1 unit (i.e., the ith individual student)
j = Level-2 unit (i.e., the jth classroom)
r_{ij} = Level 1 residual
u_{0j} = Level 2 random effect

With the following assumptions:

$$r_{ij} \sim N\left(0, \sigma^2\right)$$

$$u_{0j} \sim N(0, \tau_{00}).$$

The models for science interest with collective enterprise as the covariate of interest were the same, replacing care with enterprise. Based on these models, we examined the relationship between classroom culture (enterprise, care) and student interest in science.

4 | FINDINGS

4.1 | Classroom culture varies substantially across classrooms, but mostly not by student gender or race/ethnicity

We found that classrooms varied in the degree to which they reflected cultures characterized by collective enterprise and care (Figure 1). Specifically, classroom-level variation accounts for about 12% of the total observed variation in care, and about 7% of the total observed variation

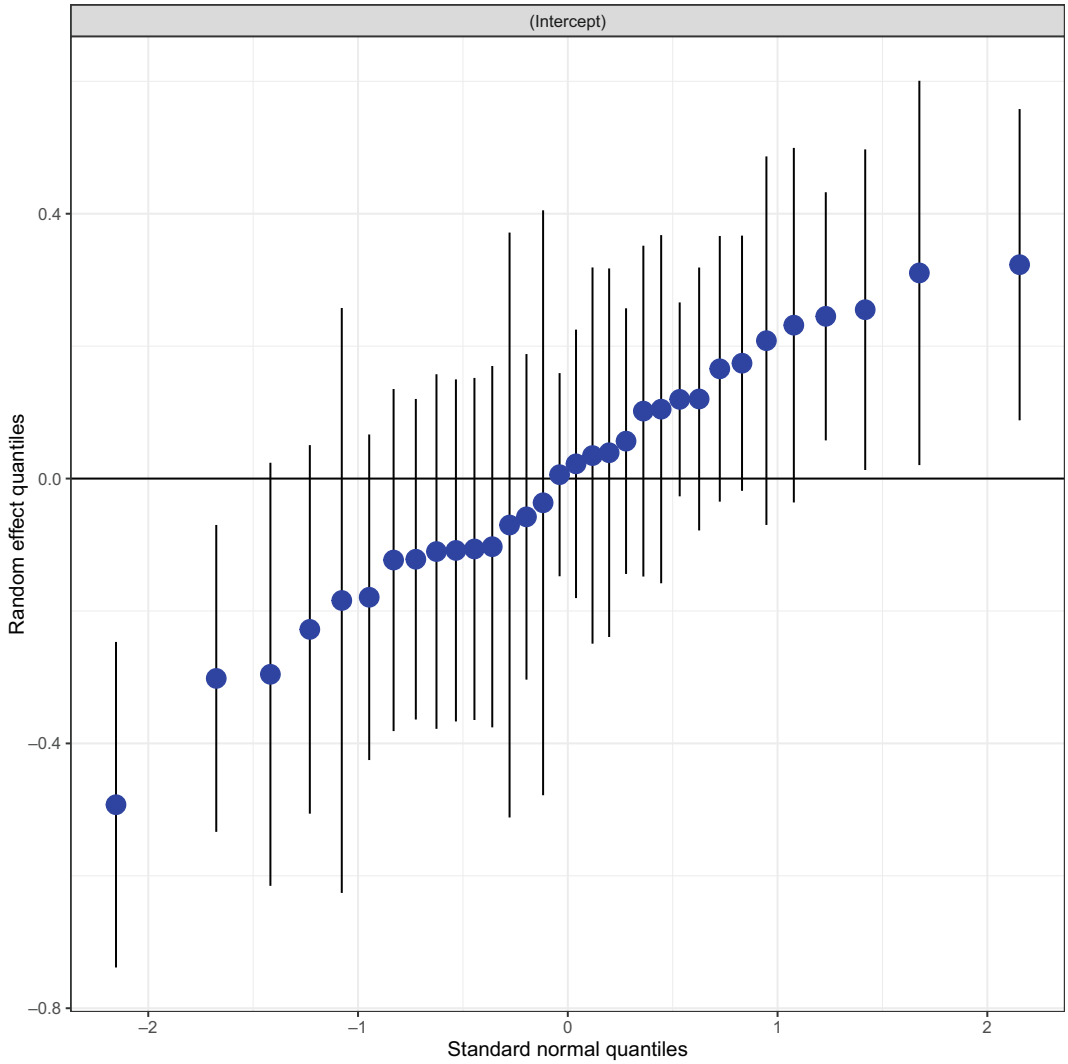


FIGURE 1 Classroom-level variation in care (intraclass correlation coefficient = 0.12).

in collective enterprise; and this classroom-level variation was significant ($p < 0.001$ for both care and enterprise) at the $p < 0.05$ level (Tables 4 and 5). We note that this degree of classroom-level variation is only slightly lower than typical rates of classroom variation in student achievement outcomes (Hedges & Hedberg, 2007), which nonetheless undergird myriad classroom-level interventions for improving student achievement. At the same time, as with achievement, the degree of variation in experiences of culture is much greater at the individual student level than at the classroom level (as evidenced by the larger values of the variance components at the student level than at the classroom level, in the models for both care and collective enterprise). The data underscore that, for students, the classroom culture was not uniform within the classroom but experienced differently by different individual students.

Although we observed student-to-student variation in experiences of the classroom culture (both within and across classrooms), we did not observe *systematic* variation in experiences based on student gender identity or race/ethnicity. That is, student background characteristics related to race/ethnicity and gender were not associated with the experiences of the classroom culture (Tables 4 and 5). Specifically, we found no statistically significant or practically meaningful differences between boys and girls in the degree to which they perceived that the class engaged in collective enterprise ($\beta_{BOY} = -0.09$; $p = 0.10$) nor in their experience of caring within the classroom ($\beta_{BOY} = 0.02$; $p = 0.75$). Some differences did emerge for non-binary students, who reported lower levels of collective enterprise than girls ($\beta_{NB} = -0.54$; $p = 0.04$); and lower levels of care than both girls ($\beta_{NB} = -0.73$; $p = 0.01$) and boys ($\beta_{NB} = -0.74$). In each case, non-binary students ($n = 9$) were about half to three-quarters of a point lower on the Likert scale responses of classroom culture than girls; however, the small sample size creates a great deal of uncertainty in the estimates and makes it necessary to interpret these results with caution.

With respect to race/ethnicity, we found no statistically significant differences between subgroups of race/ethnicity in their reports of collective enterprise or care within the classroom, at the $p < 0.05$ level. Inspecting the magnitude of the coefficients, we also do not see any differences of practical significance (even for the largest differences between groups, the point estimates nonetheless hover around 5, or "moderately agree"; and for many groups, the confidence intervals are fairly wide due to the small sample size within those categories).

4.2 | Student interest varies substantially across classrooms, but not by student gender or race/ethnicity

Our analysis revealed that classrooms varied in the average extent to which students expressed interest in science. Specifically, about 17% of the observed variation in reported student interest was attributable to differences at the classroom level, when not controlling for demographics (Table 6). This classroom-level variation was found to be statistically significant at the $p < 0.05$ level, using an exact restricted likelihood ratio test of random effects ($p < 0.001$). This analysis demonstrates that whole classrooms can be higher or lower than the overall average in terms of students expressing interest in science.

Importantly, we did not find evidence to suggest that reported student interest in science was associated with student identity (either gender or race/ethnicity) in these models. That is, on average, we did not find significant differences based on student gender or race/ethnicity with respect to reported levels of interest in science. In terms of magnitude, the value of the difference in reported interest ranges from −0.35 to 0.05 units on the interest scale, which is a difference of less-than halfway from one response to the next (e.g., strongly agree to agree).

TABLE 4 Classroom-level variation and gender and race/ethnicity differences in reports of care.

	Care 1			Care 2			Care 3		
	Estimates	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	5.17	5.04–5.30	<0.001	5.23	5.11–5.36	<0.001	5.28	5.01–5.55	<0.001
Fixed effects									
Gender (ref = girl)									
Boy				0.02	−0.10 to 0.13	0.753			
Non-binary				−0.73	−1.27 to −0.18	0.009			
Race (ref = Black)									
Native American							−0.04	−0.51 to 0.44	0.883
Asian American							−0.06	−0.47 to 0.34	0.755
Latinx							−0.11	−0.40 to 0.19	0.486
Multiple							−0.22	−0.51 to 0.08	0.145
White							−0.09	−0.35 to 0.17	0.486
Random effects									
Classroom (var)	0.10			0.06			0.10		
ICC	0.12			0.08			0.11		
N (classrooms)	33			30			33		
N (students)	836			801			821		
R^2 (marginal/conditional)	0.000/0.118			0.008/0.089			0.003/0.118		

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient.

TABLE 5 Classroom-level variation and gender and race/ethnicity differences in reports of collective enterprise.

	Enterprise 1			Enterprise 2			Enterprise 3		
	Estimates	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	4.85	4.75–4.95	<0.001	4.95	4.85–5.05	<0.001	4.93	4.68–5.18	<0.001
Fixed effects									
Gender (ref = girl)									
Boy				−0.09	−0.21 to 0.02	0.100			
Non-binary				−0.54	−1.07 to −0.02	0.044			
Race (ref = Black)									
Native American							−0.10	−0.55 to 0.36	0.678
Asian American							−0.30	−0.69 to 0.08	0.125
Latinx							−0.13	−0.41 to 0.15	0.365
Multiple							−0.19	−0.47 to 0.09	0.192
White							−0.01	−0.26 to 0.24	0.947
Random effects									
Classroom (var)	0.05			0.03			0.05		
ICC	0.07			0.05			0.06		
N (classrooms)	34			31			34		
N (students)	844			809			829		
R^2 (marginal/conditional)	0.000/0.065			0.007/0.060			0.009/0.069		

Abbreviations: CI, confidence interval; ICC intraclass correlation coefficient.

TABLE 6 Classroom-level variation in science interest and associations with student identity, grade/unit.

	Interest 1			Interest 2		
	Estimates	**CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	3.79	3.64–3.95	<0.001	4.04	3.72–4.37	<0.001
Fixed effects						
Gender (ref = girl)						
Boy				−0.03	−0.16 to 0.09	0.571
Non-binary				−0.35	−0.91 to 0.21	0.225
Race/ethnicity (ref = Black)						
Native American				−0.04	−0.55 to 0.46	0.860
Asian American				−0.19	−0.59 to 0.21	0.360
Latinx				−0.12	−0.42 to 0.19	0.450
Multiple				0.05	−0.26 to 0.35	0.758
White				0.01	−0.26 to 0.28	0.937
Grade/unit (ref = Sixth grade/cells)						
Seventh grade (Earth's resources)				−0.12	−0.41 to 0.18	0.432
Eighth grade (natural selection)				−0.44	−0.75 to −0.12	0.007
Random effects						
Classroom (var)	0.15			0.10		
ICC	0.17			0.12		
N (classrooms)	32			30		
N (students)	813			771		
R^2 (marginal/conditional)	0.000/0.172			0.039/0.159		

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient.

With respect to grade level or unit (which were the same in our analysis), we found that eighth graders (or students working with the natural selection unit) reported lower levels of interest than sixth graders (studying cells) and seventh graders (studying Earth's resources). The relationship was statistically significant at the $p < 0.05$ level ($\beta_{GR8} = -0.44$, $p < 0.01$). The magnitude of this difference in interest levels between sixth graders (cells unit) and eighth graders (natural selection unit) translates to a decrease of roughly halfway from one level on the Likert scale to the next lower level on the Likert scale, that is, from "Quite a bit like me" down to "Somewhat like me."

4.3 | Collective enterprise and care are strongly associated with student interest in science

Our hierarchical linear models showed that both aspects of classroom culture were significantly associated with students' reported interest in science: collective enterprise ($\beta_{ENT} = 0.49$,

$p < 0.001$) and care ($\beta_{CARE} = 0.57$, $p < 0.001$). In other words, a one-unit increase in reports that the classroom reflected collective enterprise or care was associated with at or more than a half-unit increase on the interest scale, that is, students identifying more strongly with statements about interest in science (Tables 7 and 8). We note that the average effect of care on interest was slightly stronger than that of collective enterprise. An examination of the marginal R^2 values shows that adding either collective enterprise (marg $R^2 = 0.23$) or care (marg $R^2 = 0.33$) to the model enables us to explain a substantially higher portion of the variation in interest than we can without those variables (marg $R^2 = 0.04$). We further explored relationships between classroom culture, equity, and interest by building models to examine interaction effects between culture (collective enterprise, care) and student identity (gender, race/ethnicity). These models allowed us to understand whether classroom culture matters more for some groups of students than others, with respect to developing interest in science. Regarding gender, we found that boys reported lower levels of interest than girls when care is equal to zero, for the average classroom and holding race/ethnicity and grade-level constant. We also found that care influenced interest more strongly for boys than girls: a one-unit increase in classroom care was associated with a 0.51-unit increase in interest for girls and a 0.63-unit increase in interest for boys, for the average classroom and with all else constant. Regarding race/ethnicity, we found that students who self-identified as "multiple" reported lower levels of interest than Black students (our reference group) when collective enterprise or care, respectively, is equal to zero, for the average classroom and holding gender and grade-level constant. The relationship between both care and collective enterprise with interest was stronger for students with multiple races/ethnicities than for Black students—that is, a one-unit increase in collective enterprise or care, respectively, was associated with a greater increase in interest for students with multiple races/ethnicities than for Black students.

5 | DISCUSSION

Our study provides evidence from a wide range of classrooms that equitable science classroom cultures support student interest in science for students with varied race/ethnicity and gender identifications, including those from populations that have been historically excluded from science (e.g., girls and students of color). Past research, primarily from qualitative case studies and ethnographies with small numbers of participants, demonstrated the importance of classroom culture for a variety of desired student outcomes in science, including equity (Aikenhead & Jegede, 1999; Bang et al., 2012; Bell et al., 2017; Carlone et al., 2011). Other research has demonstrated the benefits of collective enterprise for engaging students in scientific knowledge-building and strengthening their understanding of science (Clarke et al., 2016; Patterson, 2019); and the benefits of care for positioning students to grapple with science with the knowledge that they and their ideas are respected and valued (Krist, 2020; Krist & Suárez, 2018). We conjectured that by connecting with the cognitive, emotional, and values-related aspects of interest, collective enterprise and care might also support student interest in science. Our research substantiated this conjecture, revealing a strong and consistent relationship between classrooms reflecting cultures of collective enterprise and care, with student interest in science—a relationship that held true across a wide variety of classrooms and students.

In terms of theory, the observed relationships provide evidence for the conjecture that collective enterprise and care, specifically, might provide a mechanism for connecting with the cognitive, emotional, and values-related components of interest, thus creating opportunities for

TABLE 7 Influence of care on interest, main effects, and interactions with gender, race/ethnicity.

	Care w/interest 1			Care w/interest 2			Care w/interest 3		
	Estimates	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	0.98	0.57–1.40	<0.001	1.30	0.79–1.81	<0.001	2.08	0.70–3.46	0.003
Fixed effects									
CARE	0.57	0.51–0.63	<0.001	0.51	0.42–0.59	<0.001	0.37	0.11–0.62	0.004
Grade/unit (ref = Sixth/cells)									
Seventh grade (Earth's resources)	−0.15	−0.35 to 0.05	0.152	−0.15	−0.34 to 0.05	0.149	−0.15	−0.36 to 0.05	0.148
Eighth grade (natural selection)	−0.40	−0.62 to −0.18	<0.001	−0.39	−0.61 to −0.17	<0.001	−0.40	−0.62 to −0.18	<0.001
Gender (ref = girl)									
Boy	−0.05	−0.15 to 0.05	0.317	−0.69	−1.33 to −0.05	0.033	-0.05	−0.15 to 0.05	0.312
Non-binary	0.07	−0.41 to 0.54	0.777	−0.81	−2.71 to 1.10	0.406	0.08	−0.40 to 0.56	0.742
Race/ethnicity (ref = Black)									
Native American	0.08	−0.34 to 0.50	0.710	0.10	−0.31 to 0.52	0.634	−1.76	−4.43 to 0.92	0.198
Asian American	−0.14	−0.48 to 0.19	0.407	−0.14	−0.47 to 0.20	0.430	−0.16	−2.41 to 2.09	0.887
Latinx	−0.03	−0.28 to 0.22	0.840	−0.02	−0.27 to 0.23	0.868	−1.15	−2.71 to 0.40	0.145
Multiple	0.16	−0.09 to 0.41	0.211	0.17	−0.09 to 0.42	0.195	−1.52	−3.05 to 0.02	0.053
White	0.09	−0.14 to 0.31	0.452	0.09	−0.13 to 0.31	0.422	−0.90	−2.36 to 0.55	0.222
Interactions									
CARE × Boy				0.12	0.00–0.24	0.046			
CARE × Non-binary				0.18	−0.22 to 0.59	0.373			
CARE × Native American							0.35	−0.17 to 0.87	0.183
CARE × Asian American							−0.00	−0.42 to 0.42	0.996

(Continues)

TABLE 7 (Continued)

	Care w/interest 1			Care w/interest 2			Care w/interest 3		
	Estimates	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
CARE × Latinx							0.21	−0.08 to 0.49	0.152
CARE × Multiple							0.31	0.03–0.60	0.029
CARE × White							0.18	−0.08 to 0.45	0.178
Random effects									
Classroom (var)	0.04			0.04			0.04		
ICC	0.07			0.07			0.07		
N (classrooms)	30			30			30		
N (students)	771			771			771		
R^2 (marginal/conditional)	0.328/0.375			0.332/0.377			0.331/0.381		

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient.

TABLE 8 Influence of collective enterprise on interest, main effects and interactions with gender, race/ethnicity.

	Enterprise w/interest 1			Enterprise w/interest 2			Enterprise w/interest 3		
	Estimates	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	1.52	1.07–1.97	<0.001	1.74	1.15–2.33	<0.001	2.54	1.19–3.88	<0.001
Fixed effects									
ENTERPRISE	0.49	0.42–0.55	<0.001	0.44	0.34–0.54	<0.001	0.28	0.02–0.54	0.035
Grade/unit (ref = Sixth/cells)									
Seventh (Earth's resources)	−0.09	−0.33 to 0.16	0.495	−0.09	−0.34 to 0.16	0.487	−0.08	−0.33 to 0.18	0.560
Eighth (natural selection)	−0.41	−0.68 to −0.14	0.003	−0.41	−0.68 to −0.14	0.003	−0.40	−0.67 to −0.12	0.005
Gender (ref = girl)									
Boy	0.01	−0.10 to 0.12	0.839	−0.36	−1.03 to 0.31	0.297	0.01	−0.10 to 0.12	0.834
Non-binary	−0.09	−0.60 to 0.41	0.720	−1.74	−5.33 to 1.85	0.342	−0.11	−0.62 to 0.39	0.657
Race/ethnicity (ref = Black)									
Native American	0.06	−0.38 to 0.51	0.787	0.06	−0.38 to 0.51	0.782	−1.17	−4.06 to 1.71	0.425
Asian American	0.03	−0.33 to 0.39	0.855	0.04	−0.32 to 0.40	0.825	−0.17	−2.41 to 2.07	0.878
Latinx	0.01	−0.26 to 0.28	0.928	0.01	−0.26 to 0.28	0.931	−0.51	−2.07 to 1.04	0.517
Multiple	0.17	−0.10 to 0.44	0.225	0.17	−0.10 to 0.44	0.217	−1.80	−3.31 to −0.29	0.019
White	0.09	−0.15 to 0.32	0.477	0.09	−0.15 to 0.33	0.470	−0.87	−2.27 to 0.54	0.226
Interactions									
ENT × Boy				0.07	−0.06 to 0.21	0.276			
ENT × Non-binary				0.37	−0.44 to 1.17	0.370			
ENT × Native American							0.25	−0.33 to 0.83	0.402
ENT × Asian American							0.03	−0.43 to 0.49	0.901

(Continues)

TABLE 8 (Continued)

	Enterprise w/interest 1			Enterprise w/interest 2			Enterprise w/interest 3		
	Estimates	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
ENT × Latinx							0.10	−0.21 to 0.41	0.525
ENT × Multiple							0.40	0.10–0.70	0.009
ENT × White							0.19	−0.09 to 0.47	0.178
Random effects									
Classroom (var)	0.07			0.07			0.07		
ICC	0.11			0.11			0.12		
N (classrooms)	30			30			30		
N (students)	771			771			771		
R^2 (marginal/conditional)	0.228/0.311			0.230/0.313			0.236/0.324		

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient.

interest to blossom. Past work has argued that engaging students in collective enterprise can expand the range of ways in which students understand what it means to participate in science, thus creating more opportunities for students to see themselves as having a role within the scientific enterprise (Bell et al., 2017; Carlone et al., 2011). Similarly, past work has argued that caring environments provide students with the support and safety to take intellectual risks required for participating meaningfully in science (Krist, 2020). While additional qualitative work would be necessary to unpack the mechanisms, our research shows that these constructs are indeed related to one another at scale and thus provides initial evidence to support the theoretical foundations to explain these relationships.

In terms of pedagogy, the relationships between collective enterprise and care with interest in science underscore the importance of relationships within science teaching and learning and the importance of relational approaches to building productive science classroom cultures. Both collective enterprise and care are relational constructs that pertain to the ways that students interact with one another and with scientific sensemaking. In this sense, our research provides additional evidence to bolster calls from many researchers and practitioners about the need to place relationships at the center of efforts to create more equitable science learning opportunities for students (Aikenhead & Jegede, 1999; Bang et al., 2017; Krist & Suárez, 2018).

The observed relationship between collective enterprise and interest in science also provides support for practice-based approaches to science education where students are invited to actively engage in the scientific endeavor, participating in the collaborative sensemaking and knowledge-building processes along with their fellow students. For this collective enterprise to be equitable, all students in the classroom—particularly those from communities that have historically been excluded from science—should feel that their ideas are valued as part of the scientific conversation. This valuing of ideas is in turn reflective of caring science classroom cultures.

Beyond relationships between culture and interest, our study also establishes that science classrooms have a culture unto themselves—their own unique identity and ethos—separate from each individual's experience of the classroom. The observed degree of classroom-level variation in culture was only slightly lower than typical classroom-level variation in student achievement, typically about 12%–15% (Hedges & Hedberg, 2007). Just as research and policymaking justifiably focus on classroom-level interventions to improve student achievement, our findings also provide a warrant for investing research and development efforts around strategies for building equitable science classroom cultures. The classroom is an important lever for improving students' science learning experiences and increasing their opportunities to develop a sustained interest in science.

We know that teachers play an important role in shaping the culture of the science classroom (Supovitz & Turner, 2000) but need additional research to identify specific instructional practices that might promote equitable science classroom cultures in general, and collective enterprise and care specifically. (Calabrese Barton, Tan, & Birmingham, 2020) found that when teachers recognize and make visible students' scientific resources, the class can leverage those resources for collective knowledge-building. In their study of science classrooms, Carlone et al. (2011) similarly found that instituting a normative practice of sharing scientific ideas promoted an understanding of scientific investigation as a collaborative, generative endeavor and of scientific knowledge as shared and jointly constructed. When teachers recognize student emotions connected with systemic injustices and with science, they legitimize students' feelings of wanting to belong, to learn, and to engage with their communities in meaningful ways (Calabrese Barton & Tan, 2019). This recognition of students' emotions humanizes students and centers care as an essential component of the classroom culture.

While teachers have a crucial role to play in establishing the classroom culture, our research provides early evidence that curricula themselves may also contribute to the culture of science classrooms. The OpenSciEd curriculum was designed from the start to support equitable science learning opportunities for students. To that end, the developers emphasized equitable practice both within the professional development and in the teacher materials, with the goal of helping teachers to use equity-oriented pedagogies. For example, call-out boxes provided recommendations for soliciting student experiences with particular phenomena, for leveraging the linguistic resources of multilingual learners, and so forth. Within our sample of OpenSciEd classrooms, we found that student background characteristics (namely, race/ethnicity and gender) were not associated with student experiences of the classroom culture (i.e., reports of experiencing cultures reflecting collective enterprise and care). This observed degree of equity is not necessarily the norm for middle school science classrooms across the country (Atwater, 2000; Brotman & Moore, 2008). The equity observed within these OpenSciEd classrooms thus points to the potential power of curricula (including professional development and educative instructional materials) to support more equitable science education (Mensah, 2022; Tzou et al., 2021). Additional research is required to understand what about the curricula supported teachers to foster equitable cultures within their science classrooms.

The OpenSciEd curriculum was also specifically designed to support collective enterprise and caring environments, through the design of the instructional activities and through the use of Classroom Agreements (as described above). Our study does not provide a comparison of classroom cultures between OpenSciEd and non-OpenSciEd classrooms, and so we do not know the extent to which OpenSciEd classrooms actually reflect more collective enterprise and care than other science classrooms. To the extent that science teachers using other curricula also employ similar approaches to cultivating collective enterprise and care, the relationships with interest observed within these OpenSciEd classrooms are likely applicable in other science education contexts too. However, given the inequities that also exist in many science classrooms, it is possible that some groups of students experience more collective enterprise and/or care than others, even when the same materials are used, thus disproportionately supporting interest for certain subsets of students. Additional research is required to understand these various possible permutations connected with equity, collective enterprise, care, and interest in science education.

6 | CONCLUSIONS

Our study demonstrated that classrooms varied substantially with respect to their classroom culture; and that in classrooms where students experienced greater collective enterprise and more caring relationships, they also expressed greater interest in science. Interest in science is an outcome of critical importance because of its well-documented relationship with persistence, future course-taking, and career trajectories in science. For their part, classrooms encapsulate different cultures for science learning—cultures that are both perceptible and consequential for students. The importance of collective enterprise and care in particular underscores myriad calls, emerging from implementation research on OpenSciEd (Cherbow & McNeill, 2022; Penuel et al., 2023) and from the field more broadly (Carlone et al., 2011), for attending closely to classroom culture and the relational aspects of science learning.

Much work remains to figure out how best to cultivate science classroom cultures reflective of collective enterprise and care that support science interest development equitably for all

students. There is no question that the cultures of our larger society and of science shape the cultures of science classrooms. As such, systems-level perspectives are required to disrupt deeply entrenched inequities that infiltrate science classroom cultures. We also believe that teachers can play a role in shaping the dynamics within their classroom. And we remain hopeful that our growing understanding of equitable science classrooms will help more students, particularly those from historically marginalized communities, to find their home in the world of science.

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APPENDIX

POST HOC EXPLORATORY FACTOR ANALYSIS

TABLE A1 Eigenvalues from all 19 items using principal components analysis, showing three distinct factors.

Factor	Eigenvalue
1	8.83
2	2.00
3	1.24
4	0.66

TABLE A2 Eigenvalues for the 13 items theorized to comprise collective enterprise and care using principal components analysis, showing two distinct factors.

Factor	Eigenvalue
1	6.09
2	1.21
3	0.99

TABLE A3 Factor loadings for collective enterprise and care scales.

Item	Factor 1 loading	Factor 2 loading	Resulting scales
We work together to come up with explanations for the phenomena we are studying	0.17	0.64	Collective enterprise
We are expected to connect our ideas to the ideas of other students	0.07	0.67	
Students take each other's ideas seriously in class	0.16	0.57	
We incorporate everyone's ideas into our explanations of phenomena	0.16	0.59	
My questions/interests/wonderings influence what we do in class	0.27	0.39	
We work together with our teacher to make decisions in our class	0.35	0.42	
The teacher makes all the decisions about what we do in class	−0.06	0.13	Removed
I know my teacher will take my ideas seriously if I share	0.63	0.20	Care
All students are treated fairly	0.79	−0.05	
The teacher gives help to those students who need it	0.96	−0.15	
The teacher shows respect for everyone's ideas	0.97	−0.13	
The teacher took time to get everyone's ideas and questions	0.82	0.01	
The teacher trusts me	0.69	0.07	

TABLE A4 Eigenvalues for interest scale using principal components analysis, showing one distinct factor.

Factor	Eigenvalue
1	3.99
2	0.64

TABLE A5 Factor loadings for interest scale.

Item	Factor 1 loading
I enjoy science activities	0.84
I look forward to my science class	0.82
I am interested in the things I learn in science class	0.82
I think making an effort in science class is worthwhile	0.78
I think science will help me even when I am not in school	0.70
I think it is important to do well on science assignments	0.67