UNDERSTANDING CULTURALLY RESPONSIVE TEACHING PRACTICES IN MOTIVATIONALLY SUPPORTIVE SCIENCE CLASSROOMS

By

Anna Sansone

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ABSTRACT

Recent policies and programs in science education underscore a need to address "opportunity gaps" for students who are parts of minoritized social, cultural, or racial/ethnic groups. In order to implement professional learning for teachers to assist them in effectively supporting all students, it is critical to understand the classroom environment and practices that most equitably support students across different cultural, linguistic, or racial/ethnic backgrounds. This mixed-methods research examined the interplay of culturally responsive teaching practices and students' self-reports of engagement as teachers attempted to enact motivationally supportive teaching practices and ambitious science teaching. Participants were 7th grade science teachers ($n = 4$) and their respective students ($n = 102$) in two school districts in two different states. Data was collected over the course of a chemistry unit from classroom video observations, lesson plans, curricular materials, and student end of class reports (ECRs); school demographic data was used to examine group-level differences between student ECRs. The most frequently used supporting strategies included teachers positioning students as knowledge generators, encouragement of use and sharing of student language, valuing of students' lived experience as evidence, and support for student belonging. The most frequently observed undermining behaviors also included undermining students' position as knowledge generators and belonging support. Teachers were less likely to use strategies (either supporting or undermining) that elicited or valued student funds of knowledge (FOK) and use of students' critical lens to solve problems. Students' experiences of the classroom indicated greater dispersion (variability) in self-reports of engagement for male and nonwhite students, particularly in terms of behavioral forms of engagement. The correlation between teacher cultural responsiveness and student engagement were less clear.

Dedicated to
Mark, Amelie, and Mila
and to my students.

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CHAPTER 1: INTRODUCTION AND OVERVIEW

Chapter 11 of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council [NRC], 2012) expresses a commitment to science for all students. According to the Framework, the goal of science teaching is to give students a scientific background that enables them to understand personal and community issues and communicate scientifically, as well as to prepare students for occupations that require use of a variety of scientific practices. It also identifies a need to close opportunity gaps and provide instruction that is inclusive and motivating for diverse student groups. However, professional development and support for teachers tasked to execute this vision have not kept pace with the changing demands of ambitious science teaching. While the racial/ethnic diversity of students has increased over time (Vespa et al., 2018), the teaching population remains predominantly white (National Center for Education Statistics [NCES], 2020). There is a clear need for teachers to become conversant in strategies that support students who come from a variety of cultural, racial/ethnic, and linguistic backgrounds.

Stemming from NRC's philosophy, Appendix D of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) highlights ways NGSS could be used to equitably challenge learners from diverse backgrounds. It identifies classroom strategies for supporting seven "non-dominant" groups of students, including girls, students in alternative education programs, gifted and talented students, English language learners, students with disabilities, students from key underrepresented minority groups, and students who are economically disadvantaged. Strategies range from increasing representation and funding to community outreach and use of culturally relevant pedagogies.

Despite the fact that the *Framework* (NRC, 2012) explicitly acknowledges a need for approaches to teaching that support diverse learners, several limitations and critiques have surfaced in relation to NGSS. First, the standards themselves do not include students' identity development in science, belonging in science fields, or other affective outcomes as performance expectations or "endpoints of learning" (p. xix). Rather, they are meant to be a clear idea of what science content students should know, framed through disciplinary core ideas, crosscutting concepts, and science practices. Secondly, the approach to engineering within the NGSS is fundamentally technocratic, ignoring sociopolitical factors and instead emphasizing that engineered solutions can solve all problems (Claussen & Osborne, 2012; Gunckel & Tolbert, 2017). A third critique relating NGSS to the nature of science (NoS) suggests only limited connections to creativity and science as a way of knowing (McComas & Nouri, 2016). A final critique is that the writing committees of both the *Framework* and NGSS lacked the representation and diversity needed to develop materials and assessments that are culturally inclusive to begin with (Rodriguez, 2015) and that equity and diversity are relegated to Chapter 11 of the *Framework*, rather than being integrated as considerations throughout the document and standards (Rodriguez, 2015; Ridgeway, 2016). Notably, teachers would have to read the *Framework* itself in order to be exposed to the authors' suggestions on how to integrate equitable instruction or diversity in science teaching, meaning that educators are unlikely to fully understand or be trained on how to include diverse perspectives or equity in their instruction simply from teaching with NGSS-aligned curricula (Gallard et al., 2014).

The purpose of the present research is to understand what teacher moves and decisions might support or undermine the goals outlined in Appendix D of the NGSS for authentic and equitable student engagement in science, as well as identify areas of opportunity or challenge in implementing NGSS in an inclusive and culturally relevant manner. It will attempt to capture the practices of teachers who are actively attempting to enact motivationally supportive instruction and map the interplay between teacher practice and student engagement, with particular emphasis on the experiences of female students and students of color. Specifically, it will seek to identify the ways that teachers implementing NGSS use instructional practices that are culturally responsive, and areas where additional support may be needed for teachers to move from having a general interest in student motivation and towards pedagogies that are culturally relevant. In doing so, it will identify the areas of practical and theoretical synergy between motivational design, culturally responsive pedagogies, and equitable implementation of Next Generation Science Standards. It will also explore in greater detail the relationship between these intersecting supports and student engagement.

Disruptive Pedagogies and Teaching Against the Grain

Researchers, education reformers, and educators from varying fields and backgrounds have advocated for creation of more equitable opportunities for students to learn science, and as such, the literature and professional development resources available to researchers and teachers spans a variety of theoretical frameworks and practical approaches. The National Science Teachers' Association (NSTA) writes that:

> "equity means ensuring all students of any sex, gender identity, and/or expression, or sexual orientation—regardless of racial or ethnic background or ability—are empowered, challenged, supported, and provided full access to become successful science learners" (NSTA, 2023).

In a position paper from the National Association for Research in Science Teaching, Gallard at al. (2014) suggest using equity and diversity as a roadmap for teaching in a way that aligns with the NGSS. They advocate for a pedagogical approach to teaching the new standards that relies on community building, use of student interests to drive instruction, and inclusion of multiple ways of knowing, cultures, and experiences to support instruction for increasingly diverse populations.

A variety of lenses can be brought to bear in order to understand the teaching strategies and teacher moves that might assist science teachers in adopting this pedagogical approach. Some of these lenses draw from domain-general work in equity pedagogies (e.g. Ladson-Billings, 2014; McGee Banks & Banks, 1995) while others use domain-specific approaches to understanding science teaching (e.g. Thompson, 2016; Braaten & Sheth, 2016). Chapter 2 describes the literature and past work that have been conducted in the fields of equity pedagogies, culturally responsive teaching, and motivation research to identify areas of synergy between theoretical frameworks and to identify strategies that can be used by practitioners hoping to create equitable environments and opportunities for science learners.

In synthesizing the various perspectives on cultural responsiveness and equity in science learning, it is important to note that the terms *equity pedagogy* and *culturally responsive pedagogies* are used in different ways depending on the aims and theoretical perspective of the author. For example, Hammond (2017) identifies three dimensions of equity pedagogies as culturally responsive teaching, multicultural education, and social justice education. In her writing, only culturally responsive pedagogies focus on the way cultural responsiveness impacts students' learning and cognitive development, while multicultural and social justice education specifically address issues in the broader community. Conversely, McGee Banks and Banks (2012) conceptualize equity pedagogies as a dimension of multicultural education consisting of the strategies and environments that support culturally, racially, and ethnically diverse students—the mechanism through which social justice is achieved. They consider equity pedagogy as a component of multicultural education that cannot be practiced without attending to the other dimensions of multicultural education. Similarly, Aronson and Laughter (2016) identify social justice as the common thread uniting each of the strands of what they broadly term culturally relevant education. Within this umbrella of culturally relevant education, culturally responsive teaching is focused specifically on teacher moves that are responsive to students' home cultures, whereas culturally relevant pedagogies include teacher attitudes, dispositions, and paradigm (Aronson & Laughter, 2016).

In addition to the fact that there are varying interpretations of what it means to be a culturally responsive and relevant educator, there are a variety of ways of describing and interpreting the impacts of culturally responsive education on students' experiences in the classroom. Culturally responsive teaching impacts not only students' ability to learn academic concepts, but more broadly affects students' engagement in the classroom. Rodriguez (2015) went so far as to propose that a dimension of engagement, equity, and diversity practices be incorporated into NGSS as a way of creating learning environments that are accessible to (and effective for) all students. Fortunately, extensive research has already been conducted in the field of educational psychology to try to piece together the factors that influence students' motivation to learn, including both personal and contextual factors (e.g., Wigfield, et al. 2006; Ryan & Deci, 2000); this research provides a framework that can assist educators and researchers in understanding the precise impact of any interventions or teaching strategies on students' performance, behaviors, and values—a framework for understanding motivation. Motivation research thus offers a precise language and extensive theoretical background for measuring and understanding teaching and learning, but culturally responsive and relevant pedagogies do not draw upon the full depth of understanding provided by this field.

On the other hand, motivation literature has been criticized for describing primarily the interests and needs of white, middle-class students, or of taking a color-blind approach (Kumar et al., 2018; Usher, 2018). While motivation research is situated in educational psychology, other frames such as culturally responsive teaching additionally draw on literature in sociology and cultural anthropology. Therefore, motivation research can benefit from addressing the nuanced experiences of a variety of cultural groups and attending to issues of social justice and inclusion, while the strategies interwoven throughout equity pedagogies, multicultural education, and culturally responsive pedagogies can be better supported and explained by application of specific motivational theories.

Beyond the benefit of examining motivation research and equity pedagogies in tandem to identify areas of theoretical synergy and difference, understanding how to leverage specific strategies from across fields may help identify what kinds of professional development are needed to fully implement culturally responsive science teaching. Teachers attempting to follow Gallard et al.'s (2014) recommendation to use equity and diversity as a road map for science instruction may benefit from an understanding of which practices are easiest to integrate in a particular instructional context, where they are missing opportunities to create an equitable learning environment, and which of their existing behaviors alternately undermine or support student motivation. Teachers implementing NGSS may naturally provide opportunities for some culturally responsive practices, such as positioning students as knowledge generators in the classroom rather than as recipients of knowledge possessed by the teacher (Kolonich et al., 2011). Conversely, because of critiques in terms of the way the standards were written, it is important that teachers and researchers understand how classrooms implementing NGSS-based instruction may perpetuate—or at minimum fail to address—historical injustices in science or the sociocultural context of learning. By tracking not just student performance but also motivational outcomes for students, teachers and researchers can better understand the holistic impact of various modes of instruction on students' experiences in the classroom. A large body of research maps the relationship between a variety of facets of motivation and students' learning and achievement (Linnenbrink-Garcia & Patall, 2016). For example, motivation research describes the conditions that support or undermine student self-efficacy, mapping students' beliefs about their ability to learn and master academic tasks (Bandura, 1997). It also describes the kinds of experiences that students must have in order to develop feelings of competence in the learning environment (Usher & Pajares, 2008) or to develop interest and value for particular subjects and (Eccles, 1983; Renninger & Hidi, 2011). These competence and value beliefs predict academic outcomes.

These practices may further be enhanced in classrooms where teachers are cognizant of facets of student motivation and actively trying to support student belonging by developing a shared culture of care (Kumar et al., 2018). On the other hand, based on theoretical and practical critiques of both NGSS and motivational theory, some culturally responsive teaching practices may be missing in classrooms where teacher professional development has focused on these prevailing frameworks without intentional cultivation of practices which are culturally responsive.

Summary

The present research attempts to leverage areas of theoretical synergy between various approaches to cultural responsiveness and equity pedagogies to identify the teaching practices needed to create equitable learning environments that support students' engagement and learning. Further, it catalogues the presence or absence of those practices in existing instructional environments where teachers are attempting to enact NGSS using motivationally supportive teaching strategies. In describing *what is* and contrasting it with *what could be* in science classrooms, it presents a case for further research and professional development in cultural responsiveness in science teaching, and encourages a move from the general motivation support assumed in the written standards and into a truer enactment of culturally responsive teaching. It is hoped that this description and identification can better inform preservice teacher education and professional development and better support groups who are marginalized by culture neutral applications of NGSS and motivation research.

In the literature review presented in Chapter 2, I begin by identifying specific areas of overlap among motivation research, ambitious and equitable science teaching, and culturally responsive pedagogies. I conclude with four research questions relating to middle school science teaching in motivationally supportive science classrooms as a context for understanding what culturally responsive teaching might look in a science classroom.

CHAPTER 2: LITERATURE REVIEW

In this chapter, I outline the theoretical framework guiding the present work, beginning with a summary of literature in equity pedagogies and culturally responsive teaching. I then connect these views to present work in motivation research, identifying shared goals and areas of overlap. Then, I discuss the ways equity pedagogies specifically relate to science teaching. Finally, I identify areas of alignment among these theoretical frameworks and the associated teacher moves that might support the goals shared across frameworks. This alignment formed the basis for a coding scheme that can be used to better understand practices in science classrooms in terms of how teachers apply and support or undermine students in terms of their cultural responsiveness. I conclude the chapter with a discussion about how this broad view of cultural responsiveness in science teaching might impact student engagement and propose the use of state space grids as a way of mapping the interplay between these two concepts as a way of better understanding student experiences in science classrooms.

Perspectives from Literature on Equity Pedagogies and Culturally Responsive Teaching

A variety of theoretical perspectives inform the present research, including both domain general work in equity pedagogies, cultural responsiveness, and multicultural education, as well as work specifically done in science education to support and recognize increasingly diverse student populations. *Equity pedagogies* can be seen broadly as pedagogies that challenge conventional power relationships, conferring epistemic agency on all students and positioning them alongside teachers as a part of a community of learners (Stroupe, 2012). This approach foregrounds access, fairness, and justice and deliberately leverages the unique assets of minoritized students while recognizing the sociocultural context of their learning (Argus et al., 2022). Teachers who have skill in equity pedagogies are aware of the histories of major racial and ethnic groups, see diversity as an asset rather than a barrier, and can determine when to focus on students' individual characteristics and when to draw on culturally relevant examples and cultural artifacts in curricular design and implementation. (McGee Banks & Banks, 1995).

Early studies of *culturally responsive pedagogies* focused on teachers' abilities to leverage culturally appropriate language patterns and references for learning. In these studies, successful teachers of Native American, Native Hawaiian, and linguistically diverse students facilitated their achievement by seeing a dynamic or synergistic relationship between school and home and creating cultural match between these two environments (Ladson-Billings, 1995; Mohatt & Erickson, 1981). In many cases, this alignment was framed as a way of creating achievement gains for minoritized students (August & Garcia, 1988; Vogt et al., 1987). Even then, others called for culturally responsive pedagogies that not only tolerated but valued and supported diverse exhibitions of knowledge and means of expression (Labov, 1972; Garcia, 1993). This concept of cultural responsiveness was later expanded to include additional factors relevant to understanding the experiences of African American students such as inclusion of reciprocity, mutuality, and responsibility (Irvine, 1990; King & Mitchell, 1990).

More recently, research in culturally responsive teaching has focused on creating academic success, cultural competence, and critical consciousness for students and developing skill in community building, critical use of curricular materials, and centering students' cultural assets for teachers (Ladson-Billings, 1995; 2001). Ladson-Billings' (1995) work laid out a road map for teaching that moves from tolerance of cultural-linguistic differences and into an asset-based view of students' cultures and situates their learning in their cultural reality.

A variety of research supports the use of equity pedagogies as a way of supporting students in science classrooms. Equity centered instructional adaptations could include adaptation of curriculum, using the classroom to address issues of justice, helping students make real world connections, including diverse voices, and differentiating instruction (Seeger et al., 2022). Engaging in shared production and adoption of meaning supports teacher conceptualization of learning as an ongoing process involving student knowledge production (Ratnam, T., 2020) rather than a narrow one with clear, final, and standardized answers (Yerrick & Ridgeway, 2017). There are a variety of examples of this kind of teaching in practice.

In one study, both Māori and Western teachers were able to leverage culturally-based learning strategies and dialogue to create an environment of collaborative and reciprocal learning, termed *ako* in Māori, and *whakawhanaungatanga*, or the building and maintaining of cultural connectedness with one's family, tribe, and place. All four teachers in the study, regardless of their ethnicity, were able to facilitate connections between Western and Māori worldviews, share in the role of teacher alongside Māori elders and family members and to switch from teacher to learner depending on the cultural context of the lesson. Students responded by asking questions, taking part in collaborative learning, and understanding science from both Western and Māori worldviews (Glynn et al., 2010).

In another study, teachers leveraged beads and beadwork, local cultural artifacts in a South African township as an instructional model for understanding abstract structures of organic compounds. Students were able to leverage existing cognitive assets to problem-solve issues of representation to show bonds and patterns in molecules. In the classroom, the teacher served as a guide, not giving answers but encouraging critical thinking through a familiar medium, and as a result, students took ownership over their models, relied on one another's knowledge, self-assessed their progress, complimented one another's work, and displayed positive affect in the course (Fakoyede & Otulaja, 2020).

The teaching methods employed in each of these studies varied depending on the students' cultural context. This cultural flexibility further illustrates the assertion from a variety of researchers (e.g. Irvine & Armento, 2001; Ware, 2006) that students of color benefit from culturally specific teaching styles, indicating a need for teachers to develop both cultural competence and flexibility depending on the student groups being studied. However, this flexibility must also come with high expectations for all students. A variety of researchers (e.g. Fraser & Irvine, 1998; Vasquez, 1998; Ware, 2006; Hammond, 2014; Hinnant-Crawford, 2023), have termed this "warm demander" pedagogy: the notion that exemplary teachers of African American and other minoritized student groups display both nurturing attitudes and a culture of care alongside high expectations for students of color and the belief that minoritized students can be successful in academic environments.

Culturally responsive teaching shows a multitude of impacts both to student perceptions of the classroom environment and student learning. In one study, students of color living in rural America reported academic, cultural, and social isolation, and were aware that their personal stories were underrepresented in classroom instruction, particularly in social studies curriculum. However, the learners in the study identified that teachers who created of a culture of care ameliorated some of their feelings of exclusion and created learning environment where students felt comfortable expressing themselves and helped mitigate some of their negative academic experiences (Nganga et al., 2021). Girls from across racial and ethnic groups also showed greater career identification and identity development in STEM fields as a result of self-perception in a variety of science learning contexts (Kang, et al., 2018).

Other studies have also linked cultural responsiveness to student success on academic outcomes. For example, Powell et al. (2016) found that classrooms with higher degrees of culturally responsive instruction reported significantly higher achievement scores in reading and mathematics. Conversely, culturally and linguistically diverse students are more likely to be underserved by standardized and generalized approaches to learning (Cramer et al., 2018), as lack of consideration for cultural context has been found to lead to hidden conflict, hostility, and ineffective instruction (Irvine, 1990).

Another view that can be brought to bear in understanding the experiences of diverse student groups specifically in science classroom is *multicultural science education*. Multicultural science education reform seeks to not only acknowledge the contributions of scientists and scholars from diverse cultural backgrounds, but also to use culture as a lens through which to explain the history of science and a context for future discussion and developments (Parsons & Carlone, 2013). The goal of multicultural science education is to provide students with the opportunity to do science in a way that is relevant to their neighborhoods while developing proficiencies in understanding basic science principles, analyzing procedures and data, and applying scientific information to their daily lives (Luft, 1998). The National Science Teachers' Association (NSTA)'s position on multicultural science education has accordingly adopted tenets of multicultural science education that include incorporation of contributions of many cultures to our knowledge of science, involvement of culturally diverse children in science, technology, and engineering career opportunities, and the need for instructional strategies that recognize and respect cultural difference (NSTA, 2000).

A key approach to teaching science for equity can be found in the core practices outlined in Windschitl et al. (2012) and collectively termed *ambitious science teaching*. This approach to teaching students about the disciplinary activities of contemporary science is seen through a lens of equity and access to real-world applications. The suggested organization of activities under this framework includes introduction of a real-world phenomenon, eliciting ideas from students, engaging in activities that help students better understand the phenomenon, and then revisiting their explanations of the phenomenon. This approach has been shown to assist teachers in developing a lens of equity in science classrooms but was also limited in instances where teachers maintained a deficit view of students or illustrated a lack of critical awareness of systemic racial inequities (Kang & Zinger, 2019) or where accountability pressures constrained teachers' use of inquiry-based instruction (Hayes & Trexler, 2016; Morgan et al., 2016).

Each of these approaches shares the desire to leverage what is known of students' interests, values, and individual differences to improve student experiences in school (Gay, 2000; Hammond, 2014). Many of these pedagogical approaches specifically seek to disrupt traditional power structures, sustain minoritized cultural and linguistic groups in order to create justice for historically minoritized communities (Calabrese Barton & Tan, 2018; 2019), craft a more pluralistic society, and offer greater academic success to students in those communities (Schwarzenthal, 2018). It is also worth noting that many advocates for culturally responsive teaching demand pedagogical approaches that not only "respond" or are "relevant" to student cultures, but that actually sustain and protect those cultures and re-envision the purpose of school as an opportunity to support and protect both traditional and contemporary expressions of student culture. A full discussion of what have thus been termed *culturally sustaining pedagogies* (Paris, 2012) is outside the scope of the present research but can be seen as a further step in a progression towards understanding the relationship between school and culture.

Cultural Responsiveness and Student Motivation

While disruptive teaching and pedagogies often center primarily on methods, beliefs, and practices in teaching, the outcomes of that practice are fundamentally student-centered (Mills, 1997; Ticknor et al., 2020). Culturally responsive teaching, equity pedagogies, and multicultural education share a goal of centering student experiences and shifting power to students, particularly those who are historically marginalized in schools (Harmon, 2012). Due to the need to understand how students' experiences change over time as a result of these practices, a variety of theories of motivation can be brought to bear to explain changing student beliefs, attitudes, and values relating to learning and school.

Broadly, motivation can be defined as the process of initiating and sustaining behavior (Schunk et al., 2014); current research in motivation seeks to understand how different forms of motivation combine to shape engagement and learning (Linnenbrink-Garcia & Patall, 2018). Specifically, it seeks to understand whether students believe they can complete tasks as well as whether they value those tasks and want to complete them (Linnenbrink et al., 2016). Motivation is linked to a variety of forms of interest and engagement in classroom settings (Rotgans & Schmidt, 2011); engagement can be conceptualized as consisting of three dimensions: affective, behavioral, and cognitive (Jimerson et al., 2003; Fredricks, et al., 2004), and has been shown to have a positive relationship with student motivation and learning in both formal and informal science learning environments (Ben-Eliyahu et al., 2018; Lee et al., 2021). The precise language of motivation research can be useful in understanding students' classroom experiences.

Given the overlapping goals and understandings between culturally responsive teaching and the psychology of student motivation, it is not surprising that there is substantial overlap between motivationally supportive practices and practices in culturally responsive teaching. For example, Hammond's (2015) work on culturally responsive teaching equates what she calls "deep culture" to identity, predicated on an individual's worldview, beliefs, and values. This aligns well with Eccles and Wigfield's (2002) expectancy-value theory, which explains that students' identity and self-beliefs are formed as a result of their cultural milieu, previous experiences, and reactions and memories. In Eccles' model, students' value for activities and expectancies for success occur as a result of these self-beliefs and prior affective experiences. Hammond (2015) suggests that culturally responsive teachers support students by expressing a belief in all students' ability to master content, expressing high expectations, and addressing issues such as stereotype threat. Each of these teacher moves has also been explored in the field of educational psychology as a way of supporting a particular student outcome.

Kumar et al. (2018) provided a detailed analysis of the alignment between motivational literature and culturally responsive education. They outlined five motivational principles from dominant theories of motivation and their analogous assumptions and definitions from culturally responsive and relevant education. Notably, they combined principles connected to culturally responsive education with research from expectancy value theory (Eccles et al., 1983; Eccles & Wigfield, 2002), achievement goal theory (Nicholls, 1984; Maehr & Zusho, 2009), self-determination theory (Ryan & Deci, 2000), self-efficacy theory (Bandura, 1986; Bandura, 1997), and interest theory (Renninger & Hidi, 2011). The resulting framework is presented in brief in the first column of Table 1, and includes five key principles: *culture, meaningfulness, competence, autonomy, and relatedness*. The first principle outlined in the table is competence, which Kumar and colleagues presented in terms of both academic and cultural competence. In their framework, competence included not only to students' ability to act in the domain and classroom environment but also specifically to cultural competence, which they define as a relational construct involving ethnorelative appreciation and understanding of other cultures. They posited that teachers with high cultural competence are able to effectively assist students interweave their academic and cultural identities and use classroom tasks as a way of helping students understand sociopolitical inequities. In their framework, *autonomy* references not only self-regulation and decision making within the classroom but also personal and collective agency and critical reflection. The framework explicitly mentioned the need to question cultural hegemony and empower students to assert themselves in situations where they encounter racism and discrimination. The next principle*, meaningfulness,* included not only reference to interestingness or importance of a task but also use of content to legitimize students' culture. They described meaningfulness not only in terms of general relevance but in terms of how content should be personally and culturally relevant and should be aligned with students' values, attitudes, and cultural realities. Next, their principle of *relatedness* focuses not only on relationships with others and feelings of belonging but also relationships specifically characterized by authentic care. This vision of relatedness includes not only student to student relationships and teacher to student relationships, but connections with the broader community. Finally, the *culture* category indicates the importance of understanding how culture—and specifically race, prejudice, power, and inequity—are central to learning. They posited that educators must take a critical position on issues such as institutional racism and consider how student motivation is situated not only in the classroom but the broader sociopolitical context in which schools and communities are placed. Taken together, the framework not only mapped instructional design for motivation to culturally responsive and relevant education but also deliberately foregrounded the broader cultural context of learning, students' cultural appreciation and proficiency, and the need to legitimize students' home cultures as a part of formal learning.

While Kumar et al. (2018) thus identified the areas of synergy and agreement between the dominant social-cognitive theories of motivation and cultural relevance/responsiveness, further guidance is needed to understand what particular teacher moves and planning strategies may be used to support student motivation across each of their proposed principles. Earlier, Linnenbrink-Garcia et al. (2016) drew on many of the same motivational theories to explain broadly what is known about student motivation and emotion, identifying five motivational design principles (MDPs) that instructors may use to support student motivation. Their principles are presented in the second column in Table 1 and are aligned with the principles from Kumar et al. (2018) that are most closely theoretically aligned. Like Kumar et al. (2018), Linnenbrink-Garcia and colleagues (2016) proposed principles in support of *autonomy* (Ryan & Deci, 2000; Pugh et al., 2015), *competence* (Bandura, 1997; Usher & Pajares, 2008), and *relevance* (from Ryan & Deci, 2000; conceptually similar to Kumar's concept of *meaningfulness*), as well as having a principle relating to *belonging* (from Ryan & Grolnick, 1986 and Pugh et al., 2015; conceptually similar to Kumar's concept of *relatedness*). They further included a design principle underscoring the need to emphasize learning and understanding over competition, performance, and social comparison. In the table, I placed this principle next to culture because it addresses the social context of learning (emphasizing the need to de-emphasize competition and negative forms of social comparison), though there are key conceptual differences between Kumar's extensive discussion of culture and this design principle. While culture is not expressly included as a distinct category in Linnenbrink-Garcia et al.'s (2016) MDPs, students' ability to make connections between school and their lives outside of the classroom is a theme that is echoed across their writing, notably in the MDP relating to relevance/interest/value of work. Further, the MDP of belonging is intended to support students' positive emotional engagement. However, as Kumar and colleagues (2018) assert, culturally responsive motivation support must not only focus on students' positive relationships but proactively situate cognitive, social, and emotional development in the context of institutional structures and historical and sociopolitical aspects of culture and allow them to debate and understand biases and marginalizing life experiences. It is important to note that in the present study, participating teachers received professional learning in relation to the MDPs.

In further refinement of the work, Linnenbrink-Garcia and her colleagues more recently sought to translate these general design principles to a science-specific context (see Marchand et al., 2021). As part of this work, they added a preamble to professional learning materials designed to support the use of the MDPs in NGSS-aligned instruction that specifically addressed the alignment between the MDPs and equity (Linnenbrink-Garcia et al., 2023). It defined an equitable classroom as one where teachers "respect and embrace students' identities, helping all students feel like valued members of a science learning community" and acknowledge students' experiences and backgrounds as an asset for science learning. However, the preamble described the need to engage in continual reflection and learning in order to overcome systemic inequities, and the MDPs as toolkit that draws strategies from, but does not specifically represent cultural responsiveness. To be fully culturally responsive, teachers must intentionally recognize, value, and support a variety of ways of knowing and thinking as racial and cultural understanding and supportive instructional and interpersonal opportunity structures are key preconditions for students to develop feelings of relatedness and belonging (Kumar et al., 2018; Gray et al., 2018). Additionally, teachers who are culturally responsive must be engaged in continual self-reflection about their own assumptions, biases, and values and take a proactive role in celebrating students' contributions, value, and culture (Kumar et al., 2018). This continual self-reflection may mean that some changes to instruction are easy for teachers to make while others may be more difficult to fully implement.

Taken together, Kumar et al.'s (2018) detailed description of how motivational research enhances our understanding of culturally responsive teaching and Linnenbrink-Garcia et al.'s (2016) principles for motivational design can assist researchers in understanding not only the synergy between culturally responsive pedagogies, equity pedagogies, and motivation, but also some of the practices needed to support student motivation in culturally supportive classrooms. The following section relates some of these key themes specifically to the area of science education, identifying ways that teachers may provide domain-specific supports for equity and cultural responsiveness.

Equity and Science Education

In addition to mapping motivationally supportive teaching principles to key supports from culturally responsive pedagogies, it is important to relate these similarities to prior work in science teaching aimed at creating equitable learning environments for all students. The following sections discuss equity-related work specific to science education and continue by aligning some of the practices described in that work to the work outlined in Table 1 and described in the previous section.

Critical theorists in multicultural science education insist that, contrary to the traditional depiction of science as being objective or value neutral, educators must present science in its sociocultural context and encourage students to study not only hard data but also the questions being asked that drove collection of that data and the contexts in which scientific developments take place (Alhlquist & Kailin, 2013). As Philip and Azevedo (2017) explain, this view of what it means to provide equity in the context of NGSS goes far beyond the NRC's (2012) insistence that all students are treated equally in order to remedy past societal injustices. Rather, it forces us to acknowledge that contexts for science learning are not neutral and that existing practices simply diversify access to spaces and sectors of society that remain otherwise privileged and unjust (Philip & Azevedo, 2017). Students in an equitable classroom environment thereby become a part of a practice community where they are positioned not as lower or less powerful than teachers or "real" scientists, but rather as a part of a practice community (Stroupe, 2014). They respond to teacher expectations by sharing practices, jointly constructing knowledge, and building on and questioning one another's ideas without taking a competitive frame. Teachers can promote this kind of practice by empowering contributions from the quietest students and promoting joint responsibility for groups' thinking (Carlone et al., 2011).

Science education and education research have increasingly highlighted the importance of understanding culture as a way of promoting social justice and providing equitable learning environments (Parsons & Carlone, 2012). Many researchers in science education studying cultural responsiveness and equitable science teaching (e.g., Kolonich et al., 2018; Thompson et al., 2016; Braaten & Sheth, 2016) have written about concepts like the MDPs specifically in the science classroom; indeed, a good deal of synergy can be observed between the design principles and the work of science education scholars. Most notably, Kolonich et al.'s (2018) framework for aligning 3-dimensional learning in NGSS to equity-supportive teaching is clearly aligned to the motivationally supportive design principles. The authors explain that inclusive classrooms are not the same as equitable classrooms, and that equitable classrooms provide not only a place where students can share and critique ideas, but additionally acknowledge social and cultural dimensions of science and value students' cultural knowledge as a way to enrich the instructional environment. Their framework includes a variety of teacher behaviors and competencies.

Like Kumar et al. (2018) and Linnenbrink-Garcia et al. (2016), Kolonich et al. (2018) draw upon a variety of motivational frameworks, to include Ryan and Deci (2000)'s work in intrinsic motivation, Renninger's (2000) work in interest, Wigfield and Eccles' (2000) work in expectancy-value theory, and Schunk and Pajares' (2002) work with self-efficacy. However, they also draw on domain-specific research on the importance of inquiry and project-based learning in science classrooms (Edelson et al., 1999; Holbrook & Kolodner, 2000; Mergendoller et al., 2006) and the importance of fostering effective small groups (Cohen, 1994; Webb & Palinscar, 1996) and funds of knowledge (Moll et al., 1992; Moje, et al. 2004). They conclude that inclusive and equitable science teachers position students as knowledge generators; elicit, value, and leverage funds of knowledge (FOK); encourage use and sharing of student language; value students' lived experiences as evidence; and promote use of students' critical lens to solve problems.

Alignment between Motivational Design, Culturally Responsive Education, and Equity Pedagogies in Science

In addition to mapping Kumar et al.'s (2018) work to the design principles outlined in Linnenbrink-Garcia et al. (2016), the final column in Table 1 identifies specific practices in science education identified as supporting equity or cultural responsiveness, drawing from Kolonich et al. (2018) as well as other literature in science education as needed. Notably, in viewing the overlap among these three perspectives, it becomes apparent that the clearest alignment between the three frameworks can be seen in how they address competence, autonomy, and meaningfulness. Kolonich and colleagues' first framework element relates to the importance of positioning students as knowledge generators, and framework element 3 encourages use of student language to affirm students' contributions. Both of these elements are aligned with the goals of promoting students' competence while de-emphasizing competition. Next, framework element 5, promoting students' use of critical lens to solve problems, is aligned with the principles promoting autonomy in the other frameworks in that class is centered on students' thinking with the aim of developing students' agency, critical consciousness, and ability to evaluate ideas and critique work. Third, framework elements 2 and 4 can be seen to support students' perception of meaningfulness or personal relevance, in that they suggested that students experiences outside the classroom and funds of knowledge (FOK) should be leveraged to create learning environments that enable students to actively identify with content and find personal and cultural relevance in class discussion.

Alignment is less complete in the areas of belongingness and culture. Both Kumar et al. (2018) and Linnenbrink-Garcia et al. (2016) have specific conceptual categories for relatedness or belonging, Kolonich, et al. (2018) does not, and while culture is a central component in Kumar et al. (2018), it is not as explicitly addressed in either Linnenbrink-Garcia et al.'s motivational design principles or Kolonich et al (2018). The motivational design principles address classroom culture through their discussion of belonging and emphasis of a learning orientation (rather than a competitive one) and the Framework discusses the importance of students developing a critical lens, but these are less oriented towards explicit discussion of historical and sociopolitical factors that play into science and science teaching and learning. While relatedness and culture are therefore not incongruous with the literature on equity pedagogies in science teaching, this theoretical difference may provide insight into the existing limitations of science teacher professional development and practice. If teachers learning to implement "equitable science teaching" address other dimensions of student motivation without centering macro-level context affecting student belonging and cultural competencies, a key theme in culturally responsive pedagogies is omitted, potentially to the detriment of students for whom white, Eurocentric curricula is least accessible.

As science teaching is considered from the perspective of cultural responsiveness and design for motivation, a theme emerges that it is important to not only generally support student motivation but to explicitly acknowledge the sociopolitical contexts in which science is taught, learned, and conducted. Teachers create and influence many of norms and routines in a classroom that influence how students perceive themselves and the classroom environment, and their actions can either assist students in engaging with scientific practice or undermine their engagement. Engagement is impacted by a variety of contextual factors that include elements of students' culture and require understanding their experiences as members of minoritized groups and their cultural experiences and learning assets. Both classroom structures and the social environment strongly influence how students develop an identity in relation to an academic field such as science (Calabrese Barton, et al., 2013). Opportunities to feel cared for and respected and to have a sense of belonging are important for all students (Van Ryzin et al., 2007) but is of particular importance to students of color in light of the many experiences that students have of being alienated in school and academic domains (Morocco et al., 2002; Parsons, 2005; Gray et al., 2018). Further, parents influence and facilitate student engagement and have a strong impact on how children perceive their own abilities and the value of learning (Eccles et al., 2006). If there is discontinuity between the values and cognitive and social repertoires developed by students of minoritized groups and those presented and emphasized in school, students' engagement may decline (Tyler, et al. 2008), or students may actively choose not to engage in school as a way of "disidentifying" with oppressive or discriminatory environments (Ogbu, 1992; Steele, 1997).

A variety of teacher practices have been identified which support student motivation in classrooms that are intended to promote equity or illustrate cultural responsiveness. For example, Calabrese Barton and Tan (2020) identified that teachers should work not only to include all students in classroom activities, but to make issues of justice and injustice visible, intentionally disrupting traditional power structures in the classroom and in communities and positioning themselves alongside students as learners. They cite Davis and Schaeffer's (2019) studies of 4th and 5th grade classrooms where Black students learned about water not only in terms of its decontextualized molecular properties but also as a compromised resource in Flint, Michigan. In the study, students' sensemaking episodes allowed them to understand not only water but also key issues in environmental justice and the sociopolitical context in which water is shared (or withheld) as a resource. In their own work, Calabrese Barton and Tan (2018; 2019) also found that engineering challenges provided opportunities for students to solve problems of concern in the classroom. A key feature of the teacher's work in their study was the ability to position herself alongside her students as a learner and guide, similarly to the way the teachers in Glynn et al.'s (2010) study of Māori and western science learning positioned themselves both as guides and learners, sharing leadership with Māori elders in a unit designed to help students understand both western and tribal views of science and the natural world. The teachers in both studies engaged students in learning that was authentic and created a learning environment where students' cultural realities were not only acknowledged, but embraced and supported. Gay (2018) describes this kind of behavior as explicit teaching of how to know and praise one's own and one another's cultural heritages, explicitly teaching respect for differences.

Examination of the relationship between practices recommended across a variety of frameworks for teacher practice and self-reports of engagement of female students and students of color may further help capture the experiences of underrepresented groups in classrooms that are meant to provide them with supportive learning environments. An intersectional view of equity (Crenshaw, 1989; Rosenthal, 2016) further requires that we examine not only the classroom moves but the experiences specifically of students who are members of multiple marginalized groups in order to fully understand the ways in which instructional practice is perceived. Many students learn in contexts in which they have multiple intersecting identities, which may place them at the margins of formal academic environments. For example, Black women and girls' experiences in science are shaped simultaneously by racial and gender expectations (Ireland, et al., 2018). Understanding how Black girls' experiences differ from Black male, white female, and white male experiences further elucidates how classroom environments influence engagement for marginalized student groups. For example, Reznik et al. (2023) found that creation of informal science learning spaces that allowed young women to experience STEM in welcoming environments, see examples of role models and peers with diverse racial, gender, sexuality, class, and ability levels, and to participate in projects relevant to their families and communities, fostered a feeling of security and a greater willingness to engage in scientific conversations. Aldridge and Rowntree (2021) found that students' perceptions of the learning environment in science had signification relationships with their motivation and self-regulation. A variety of lenses can be brought to bear to understand students' experiences in these formal and informal learning environments, and the aforementioned studies are situated alternately in motivational research, equity pedagogies, or cultural responsiveness, depending on the focus of the study.

Understanding Teacher Practice and its Relation to Student Engagement

One way to understand the long-term interplay of teacher behavior and students' engagement is to compare culturally responsive teacher behaviors to students' perceptions of the classroom both on a class-by-class basis and over time. Further examining these patterns specifically for students of color may shed additional light on how changes to teacher practice impact students who have been historically excluded both in science and science classrooms and is in line with current imperatives that motivation research be expanded specifically to describe and understand the experiences of students of major non-white racial and ethnic groups (Gray et al., 2018; Usher, 2018). This kind of longer-term comparison enables both description of practice and exploration of the dynamic relationship between teacher practice and student motivation.

Students' experiences in the classroom can be catalogued through mapping their behavioral, emotional, or cognitive engagement. Behavioral engagement relates largely to students' participation in activities and compliance with teachers' directions; emotional engagement captures students' positive and negative reactions to teachers, students, and the environment; cognitive engagement relates to students' investment in activities and willingness to work to understand difficult concepts and master challenging skills (Fredricks et al., 2004). In line with suggestions in the frameworks detailed previously, engagement has previously been mapped to a variety of motivationally supportive practices such as provision of autonomy and support for student value of content and is influenced by the interpersonal environment of classrooms (Blumenfeld et al., 2006; Turner et al., 2014).

Teacher instructional strategy use may influence one type of engagement at the expense of another, or one type of engagement may precede another over time. For example, when teachers enact instructional strategies that support students' feelings of belonging, students may report higher emotional engagement, whereas if teachers effectively tap into students' lived experiences and funds of knowledge, students may be more likely to exhibit cognitive engagement. Either of these may result in subsequent behavioral engagement their motivation for science develops. Conversely, teachers who exhibit controlling strategies may elicit student behavioral engagement (compliance) without commensurate emotional or cognitive engagement. However, prior research has not fully examined these specific patterns in relation to specific strategies in culturally responsive teaching.

In this regard, it is important to study changes in teachers' behaviors over time and in relation to students' reactions to that instructional behavior: whether certain strategies are used more consistently than others, whether opportunities are consistently missed, and how these patterns in strategy map to students' engagement over time. A variety of approaches can be used to understand how changes to interactions and perceptions in the classroom change over time, from in-depth longitudinal study of teacher practice (e.g., Johnson, 2011) to surveys of students' and teachers' perceptions of one another's behaviors (e.g., Mainhard et al., 2011) or mapping of moment-to-moment behaviors and interactions (e.g., Pennings, et al., 2014a, 2014b).

Mapping Teacher Practice and Student Engagement in a Dynamic System

A dynamic systems (DS) approach may assist us in understanding patterns in student engagement and their relationship to teacher practice. Dynamic systems (DS) theory is one approach to understanding how interrelated moment-to-moment processes can organize into patterns occurring over minutes or hours which in turn lead to patterns that continue to develop over the course of months or years. This approach to understanding student motivation has been recommended as a way of understanding how immediate experiences interact with historical experiences, existing motivational schemas, and short-term moods in relation to a new learning situation (Ainley et al., 2005; Ainley, 2012) and as a method of better understanding the complex and dynamic processes that shape both cognition, motivation, and emotion and interpersonal relationships in classrooms, on teams, and in families (Hilpert & Marchand, 2018).

Using a DS approach to understanding teacher behaviors and student engagement allows us to see the dynamic interplay between moment-to-moment thoughts, feelings, and interactions and higher order dispositions about a particular learning environment or subject and to understand changes over time as they occur over a variety of time scales. For example, emotions experienced at a time scale of seconds or hours may lead to moods, which in turn contribute to the broader development of personality. According to DS theory, these time scales mutually enforce another. In the prior example, emotions may lead to moods but moods can also dictate moment-to-moment emotions, indicating a dynamic interaction of processes at different time scales (Hollenstein, 2013). Similarly, teacher behaviors that take place from moment to moment cumulatively influence student dispositions as students form academic identities and perspectives, while moment-to-moment student engagement may reciprocally influence teacher strategy use and behaviors.

In a DS model, certain states are more probable than others: so-called *attractor states*. From a systems perspective, this can be seen as the state where the system prefers to reside. In the classroom environment, this might be a teacher's default or most comfortable teaching practice, strategy, or response to a given situation. On the other hand, a *repellor state* is a state which is unusual or less likely, and whose existence can be easily disrupted by a return to the attractor state. This might be use of a strategy that is not currently engrained in a teacher's current practice and which a teacher finds difficult to implement. By viewing behavior as a dynamic system of fluctuation between attractor and repellor states, we can understand how systems change by examining the stability of various states (Thelen & Smith, 2007).

Using this approach to understanding classrooms enables us to visually represent changes to teacher practice over time and assists us in understanding how interactions can form the foundation for relationships between teachers and students. This approach was previously used by Pennings and Hollenstein (2020) to compare teachers' interpersonal style to classroom behaviors using nine different interpersonal typologies. Turner and Christensen (2020) used dynamic systems as a way of understanding patterns in teacher-student interactions after creating a "perturbation" of previous attractor states (i.e., a change from traditional teaching practice to more motivationally supportive strategies). Dynamic systems have also previously been used to understand how a science teacher's professional identity was shaped across professional learning experiences to become more inquiry based, showing that teacher practice and identity are also constantly shifting because of professional learning and classroom experiences (Garner & Kaplan, 2018). Eun (2011) identified student cultural resources as an asset that helped teachers better understand classroom practice and shift towards more effective classroom practice, indicating that teacher practice and student characteristics may mutually influence one another. The present research draws on these approaches to compare teacher behaviors to student engagement with the aim of understanding how teacher practice and student engagement serve as a dynamic system in the classroom.

The Present Study

Given the overall synergy between the research on culturally responsive pedagogies, equity pedagogies in science education, and principles for designing motivationally supportive instruction, it is reasonable to assume that teachers attending to instructional planning using design for motivation may create classrooms that are by nature equitable and engaging and incorporate contributions from all students. However, as noted above, teachers may find some pedagogical practices/shifts easy, while others may take more time to develop, and some pedagogical shifts may be inhibited by teachers' own biases or lack of awareness, and still other culturally responsive teaching strategies may not be apparent because they are not integrated into existing approaches to science teaching. As McGee Banks and Banks (1995) point out, "the implementation of strategies such as… culturally relevant instruction within the context of existing assumptions and structures will not result in equity pedagogy. Instead, current assumptions… must be interrogated and reconstructed" (p. 153). They explain that teachers may be blind to their own biases or commission of microaggressions since they are so institutionalized within society. For this reason, it is important to understand not only what clusters of behavior exist in teacher practice, but also what undermining behaviors or missed opportunities exist in instruction that could be addressed through additional professional learning, reflection, or reinforcement over time.

The present research takes advantage of an existing context where teachers were attempting to enact motivationally supportive practices in NGSS-based science instruction and uses the lens of culturally responsive pedagogies to attempt to understand whether these practices are related to engagement specifically for female students and students of color, identifying and distinguishing trends for white male, white female, URM male, and URM female students. Teachers in the study received training in motivational design, which—as noted in the literature review—has substantial theoretical overlap with culturally responsive practices, but does not foreground issues of equity and diversity per se so much as a general attention to student motivation in the classroom.

Identifying which culturally responsive practices manifest in motivationally supportive classrooms, which practices are absent, and where practices may undermine engagement for different student groups will facilitate understanding of what additional education/support teachers might require to become more culturally responsive in addition to broadly supporting student motivation. Towards this end, the present research examined clusters of teacher discourse and behavior for patterns and attempted to identify relations between culturally responsive teaching strategies and students' daily self-reports of engagement. Prior research has illustrated the importance of providing opportunities to support historical and cultural meaning and belonging in the classroom, and that these opportunity structures are particularly important for Black students (Gray et al., 2018).

The present mixed-method study examined the instructional moves for four middle school science teachers across classroom episodes and their students' corresponding self-reports of engagement in order to understand how culturally responsive practices may manifest in motivationally supportive classrooms, what practices might be absent from practice, and how these teacher practices are related to student reports of motivation. Specifically, it set out to answer the following questions:

> *RQ1:* What patterns/themes relating to culturally relevant pedagogies exist in teachers' planning, strategy use, and discourse while implementing NGSS in classrooms where teachers are attempting to enact motivationally supportive instruction?
>
> *RQ2:* What patterns/themes exist in teachers' planning, strategy use, and discourse that lack alignment to culturally relevant pedagogies and may undermine cultural responsiveness?
>
> *RQ3:* Does teachers' use of culturally relevant strategies map in any particular pattern over time against students' daily end of class reports of engagement?
>
> *RQ4:* Is there a difference in the results to RQ3 for groups considering intersecting gender and racial identities (URM vs. non-URM, male vs. female)?

Due to the exploratory nature of the study, I did not have a specific hypotheses for each research question; rather my objective was to try to understand and document teaching practice and identify/understand any patterns in student engagement.

CHAPTER 3: METHOD

Design

The present study sought to catalogue the predominant teaching strategies for four teachers teaching the same standards in middle school chemistry units and to compare those strategies to students' end-of-class self-reports of engagement in order to understand the interplay between motivational design and cultural responsiveness. Teachers began their experience with summer professional learning in a pilot program designed to help them implement motivationally supportive practices in middle school science classes (from Linnenbrink-Garcia et al., 2016) and then implemented a science unit and received feedback on their instruction as a part of a broader research project. Classroom video and student engagement reports were used to catalogue and understand teacher practice and student engagement. To combine qualitative and quantitative data, the study used a convergent mixed methods design (Creswell, 2015) culminating in four qualitative cases and using State Space Grids to present trends in student engagement.

During the study, I served several roles. First, I assisted teachers during their professional learning in understanding the motivational design principles in the context of science teaching. Like the teachers in the study, I am a science teacher and have experience teaching NGSS, to include the same standards that the teachers were teaching during the study. In addition, as a doctoral student studying motivation, I am familiar with the language and principles of motivation, which uniquely positioned me to understand both teachers' perspectives and the aims of their professional learning on motivational design. While Amanda and Steve implemented their chemistry units, I also served as a member of the research team offering them feedback on their implementation of the motivational design principles. After the conclusion of their teaching, I selected classes from each teacher to code qualitatively based on the available data and my own perceptions of what constituted “typical” breadth in teaching practice over the course of a unit. Like two of the teachers in the study, I am a white female, and like all the teachers, I am familiar with the challenge of facilitating science learning for students who may historically be excluded from science and have marginalizing experiences in formal learning. I also have a high degree of personal interest in making students’ classroom experiences personally and culturally relevant and have spent a large portion of my professional career seeking alignment between mandated content standards and curricular resources, my own understanding of what scientists know and can do, and what I think is most relevant and meaningful for my students. I recognize that this positionality simultaneously gives me a unique perspective from which to understand the teachers and teaching practices in the study and carries with it cultural, personal, and professional bias. The teachers in the study are at once research subjects and my peers, and as I made observations and drew conclusions about their work, I found it important to repeatedly ask myself to consider my conclusions both through the lens of a researcher and through the lens of a professional educator. To minimize the impact of my own biases on the results of the study, I discussed my coding and observations with my advisor, compared my qualitative codes to the feedback provided to the teachers by the broader research team during implementation, and shared my qualitative cases with another researcher familiar with the study for confirmation, seeking agreement across multiple perspectives. In doing this, I attempted to balance my own expertise in the subject matter and theoretical framing of the study with the need to take into consideration my own biases and how they may have impacted my interpretation of classroom vignettes.

Participants

Participants were four middle school science teachers, two each from a midwestern state and a southwestern state in the United States, and 102 students in their respective 7th grade science classes who gave parental and student consent to be a part of the larger research study (demographic breakdown for each classroom in Table 2). Teachers in the project self-identified as being interested in motivation and were in various phases of adopting Next Generation Science Standards. Each teacher received professional learning, implemented what they learned in terms of how to support students' motivation through instructional practice during their 7th grade chemistry unit in the same school year, and assisted with student data collection and classroom video recording during their unit of study.

Teachers

All four teachers in the study were relatively experienced, having between 13 and 23 years of classroom experience. All the teachers described themselves as 'somewhat comfortable' or 'very comfortable' implementing NGSS in their classrooms and expressed the belief that it was 'somewhat true' or 'very true' that no matter what they did in the classroom, society would leave some students out of science. The teachers self-selected into a research study to learn more about how motivational instructional supports can support student motivation and help them learn science. Two teachers (Caroline and Amanda) were from the same large school district in the American southwest with different socioeconomic and demographic characteristics; two teachers (Steve and Sandra) were from two different, smaller school districts in the Midwest. I selected them from a larger group of six teachers in a broader research study into motivational design because of their comparable levels of experience and to enable me to explore how culturally responsive motivational support might work in two different states using two different curricula and in classrooms with varying degrees of cultural diversity.

As a result of their involvement in a larger study for which these data were collected, teachers received training on how to infuse motivational design principles (from Linnenbrink-Garcia et al., 2016) into their planning and instruction and ongoing feedback in their integration of these principles into NGSS-aligned instruction. Specifically, they received training on motivation theory as well as instructional design in support of motivation over the course of a 4-day professional development institute in the summer of 2019. During this time, they also participated in co-design of resources to eventually assist other in-service teachers in creating motivationally supportive classes. During the 2019-2020 school year, the teachers recorded class sessions during their respective chemistry units, and the research team gave them feedback on their instruction. Cultural responsiveness was not explicitly discussed with the teachers during the initial institute, though it was addressed in a later iteration of the training.

Students

A total of 102 students from four schools participated in the research, and class demographic composition varied depending on the school/teacher. In Caroline's class, 24 of the 36 students in the study were white, with the remainder identifying as multiracial, Native American, or Latinx. In Amanda's class, all students were nonwhite, 20 identifying as Hispanic/Latinx, with one student each self-reporting as Black, multiracial, or Native Hawaiian/Pacific Islander, and two self-reporting as Asian. In Sandra's class, 19 students were Black and one was white. In Steve's class, 14 students were white and 7 were nonwhite, with the nonwhite students identifying either as Black or Latinx. Further school-level demographic data can be found in Table 2. All the students in the study were in 7^{th} grade during the 2019-2020 school year.

Classroom context

The teachers in the study used two different curricula in support of student learning. Caroline and Amanda, who both taught in the same district, used a district-created curriculum. Their chemistry unit took place at the very beginning of the year, and as such their videorecorded classes take place between August and October of 2019. Steve's school district had formally adopted the IQWST curriculum with the unit centered around the question, "How can we make new stuff from old stuff?" (Krajcik, Reiser, Sutherland, & Fortus, 2012). Sandra's district did not have an official NGSS-aligned curriculum so the research team purchased IQWST for her to use in her classroom. Therefore, while Steve and Sandra were not in the same school district, they were using the same curricular resources. Their chemistry unit took place later in the year, so their class sessions recorded in the study ranged from December 2019 to March of 2020.

Both the district created unit and the IQWST curriculum focused on NGSS disciplinary core ideas and crosscutting concepts relating to energy, energy transfer, and the conservation of matter, specifically in relation to MS-PS1-6, which challenges students to "Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes" (NGSS Lead States, 2013). During their units, all four teachers worked with their students to establish chemical vocabulary and conducted a series of labs, discussions, and learning activities to help their students understand chemical change.

Data Sources

Data were collected from several sources during the study. First, class sessions for each teacher were recorded over the course of the unit so that teachers could discuss their planning with researchers as a part of the larger study. In addition to classroom recordings, students completed end-of-class reports (ECRs) on assigned days to track their perceptions of the classroom environment. Student responses to items relating to student engagement from the end-of-class reports (see Table 3) were collected at the end of each class that was videotaped. The student self-reported engagement was used to examine the degree to which teacher behaviors mapped to student motivation and engagement.

Students responded to two questions relating to each construct. I created a mean score of the two items to represent students' engagement across each of the four dimensions for each class period. Items measuring behavioral engagement and disaffection were taken from Skinner et al. (2009) and have previously been validated in a variety of contexts as a way of understanding students' positive and negative behaviors in school (Skinner et al., 2008; Ritoša et al., 2020). Items measuring cognitive engagement were taken from Fredricks et al, 2016 and were developed specifically in the context of math and science engagement. Items relating to students' affective engagement were taken from Linnenbrink-Garcia et al., 2010. While it is not possible to validate these two-item measures in the context of the present study, the items were taken from a larger project that included full scale validation; use of shorter two item measures for ECRs is a common approach for experience sampling methodology including end of class reports to capture participants' experiences without overburdening respondents without use of lengthier questionnaires (Hektner et al., 2007).

All teachers captured at least 10 classes on video that had corresponding ECRs over the course of their unit; from this sample, four videos with associated ECRs were selected for each teacher to track teachers' behaviors as well as students' responses over the course of the unit. Instructional sessions were selected both for the diversity of scientific practices they represented (e.g., asking questions and defining problems, planning and carrying out investigations, analyzing and interpreting data, engaging in argument from evidence) (*Appendix F*; NGSS Lead States, 2013), as well as to offer an idea of how students' learning might be supported over the course of a unit: the video cases for each teacher captured both lab and discussion and took place at the beginning, middle, and towards the end of the unit in order to capture the greatest breadth of teacher practice. The present research therefore focuses on four classes per teacher (16 classes total) as the basis for qualitative coding and analysis of student engagement. Each classroom episode was approximately 45-50 minutes in length, so each teacher's case was developed from approximately 180 minutes of instructional time. I created transcripts for each classroom video for ease of highlighting codes and to assist in compiling examples for each code.

A variety of other supporting materials were used to contextualize the classroom videos and ECRs. Teachers shared lesson plans and curricular materials throughout data collection indicating the planned instructional sequence and, on occasion, planned changes/deviations to better support design for motivation. Examination of these lesson plans assisted in identifying any modifications or adjustments that teachers made from the scripted curriculum to support student motivation. Additionally, throughout implementation of the study, the researchers generated observational summaries for selected class periods as a way of giving teachers feedback on their implementation of the motivational design principles. These summaries were used throughout qualitative coding as a further informational source to assist in triangulating data and ensuring that key ideas were consistent with those from other researchers observing the same class sessions and teachers.

Finally, demographic information was obtained from institutional records and checked against student survey responses. This institutional data was used to compare responses from students who identify as belonging to minoritized groups to their white peers.

Data Analytic Plan

Prior to coding the videos, I developed an *a priori* coding scheme by synthesizing the conceptual categories of supports (an associated instructional moves) from the literature sources identified in the literature review (Table 4). Specific strategies in the preliminary coding scheme are organized according to the framework proposed by Kolonich et al. (2018), with additional detail from Gay (2010; 2018), Windschitl (2012) and other work in equitable science instruction, as cited in the table. I organized the strategies according to the framework that was most directly aligned to science education, though as noted in the literature review, there is a good deal of conceptual overlap between the principles in the framework, instructional design for motivation, and culturally responsive and relevant education. This ensures that descriptors added to clusters of behaviors are aligned to the conceptual framework while ensuring that examples come from a variety of resources in culturally responsive pedagogies. In acknowledgment that there is no framework element that aligns to the relatedness/belonging concept in the MDPs and the importance in culturally relevant pedagogies of establishing positive relationships with students, an additional category, *belonging and culturally relevant caring* (from Parsons, 2005; Hammond, 2014) was added to capture teachers' behaviors relating to intentional development of positive relationships between students and between teachers and students. The additional category was needed to fully capture the way justice-oriented educators not only teach the Performance Expectations (standards) but in fact leverage classroom experiences to serve student and community needs, fulfilling the vision of a democratic education outlined in the Framework even when it is at odds with the occasionally technocratic way the standards are written.

The resulting categories in the coding scheme are as follows: positioning students as knowledge generators; eliciting, valuing, and leveraging funds of knowledge (FOK); encouraging use and sharing of student language; valuing students' lived experiences as evidence; promoting use of students' critical lens to solve problems; and belonging/culturally relevant caring.

An overview of the qualitative coding procedure can be seen in Figure 1. In order to answer the first research question relating to behaviors that were supporting of students, I first examined each video, coding classes using NVivo 13 software program for supporting practices. Coding was done using the transcripts for each class so I had a text record of the specific examples in each lesson. The purpose of preliminary coding was to catalogue the strategies used by teachers in each class period. During this preliminary coding, I began with the provisional list of strategies (see Table 4) aligned to the theoretical framework and research questions of the study but remained open to inclusion or addition of strategies not expressly identified *a priori* for coding. During this time, I used descriptive memos to record any questions, thoughts, or observations about teacher strategy use that may have assisted in revealing strategies that may not fit with the categories I previously identified. This enabled me to determine whether my preliminary coding scheme captured the full breadth of strategies that teachers might use or whether additional categories were needed to capture culturally responsive teacher practice.

There was only one instance where my preliminary coding scheme did not fully capture teacher practice. Specifically, Caroline frequently made explicit the cognitive and material resources that successful students needed to rely on to be successful students. I added this practice (italicized in table) to belonging and culturally relevant caring. This strategy also supported students in developing autonomy but was listed as an example of belonging support because of the way Caroline used the strategy to help students work together as teams and understand the strategies required to be a successful student in a formal learning environment. After this practice was added, I revisited all prior codes to ensure that they aligned with the revised coding scheme.

To answer the second research question relating to undermining behaviors, I made a subsequent pass through the data (see Figure 1, procedure), classes were coded to identify any undermining behaviors as identified in the literature. No additional codes beyond those listed in the *a priori* coding scheme were needed for undermining behaviors. I felt confident that I had reached theoretical saturation in the context of the present cases generally towards the third or fourth class period for each teacher, when behaviors observed generally exhibited the same patterns as the previous classes and additional examples of teacher behaviors were primarily different examples of the same strategies as preceding lessons/instructional instances.

I compiled strategies across all four teachers to create a summary of the key strategies used across the study. By examining the tables and looking for themes across teachers as well as instances where codes did not have a high number of examples, I was able to identify not only patterns across all four teachers, but areas of omission where none of the teachers had consistently employed supportive strategies, which might be an area where additional professional development would help change teacher practice. When I had finalized the four resulting qualitative cases, I shared them with another researcher who worked extensively with teachers in their classrooms and who was familiar with NGSS-based instruction and culturally responsive teaching. I used the feedback I received to clarify the language in the cases.

After coding all four teachers' classes, I revisited each teacher's qualitative codes, developing a summary table for each teacher showing representative samples of strategies used across all four instructional instances. I then assigned each class period a magnitude code of "high", "medium-high", "medium", "medium low", or "low". Magnitude coding is appropriate for qualitative and mixed methods research that requires additional texture or detail and involves adding a supplemental symbolic code such as *strong, weak, or negative* to an existing code (Saldaña, 2016). In this case, codes were assigned on the basis of frequency and diversity of supporting behaviors versus frequency and diversity of undermining behaviors and enabled me to compare behaviors between class sessions. Specifically, "low" codes were assigned to class sessions whose teacher moves included a greater balance of traditional practices such as use of language only from the curriculum, requiring that all students follow the same procedure, or a larger number of undermining behaviors such as controlling language. Class sessions that received a magnitude code of "high" illustrated a wider breadth of strategy use as well as more frequent application of strategies across conceptual categories with few to no undermining codes. Class sections assigned a "medium" code had a mix of supporting and undermining practices, had just a few examples of supporting practices that were inconsistently applied, or had little diversity in strategy use. In cases where teacher behaviors feel in between "medium" and "low" I scored the class section "medium-low" and in cases where teacher behaviors fell in between "medium" and "high" I assigned the class a score of "medium high".

In some cases, it was challenging to assign these codes as the reasons for the codes varied from teacher to teacher and class to class. On the one hand, classes were easily coded as "high" when teachers used multiple types of support with few to no undermining examples. Similarly, classes where there were overt power struggles or predominating examples of controlling language were easy to qualify as being "low" for cultural responsiveness. On the other hand, situations where there were a mix of undermining and supporting behaviors, or where a teacher used just one or two strategies repeatedly without variety were a bit more ambiguous. During this time, I also grappled with the fact that different behaviors may not have had equal impact on students' experiences of the classroom. For example, a negative interpersonal interaction around misbehavior would likely have a greater undermining impact on students' experiences of the classroom than a teacher's use of a lab with scripted outcomes. It is also possible that individual students' perceptions of the supports and undermining examples may have differed depending on whether or not they were involved in a particular interaction. For example, in a class otherwise noted as being "high" for motivational supports, a single negative interaction between the teacher and a specific student could have completely changed that student and/or their peers' perception of the class. In creating the magnitude codes, I tried to take into consideration the varying impacts of each coded example on student experience and the overall impact to the learning environment when the codes were taken into consideration together.

In order to answer the third and fourth research questions about how teacher practices map to student engagement, I began with the assigned magnitude coding ("high" to "low") to capture teacher practice. I cleaned and processed student engagement data and calculated descriptive statistics using SPSS (Version 28) and created individual student trajectory files for Gridware using a combination of SPSS and Excel. Gridware is a statistical software package that displays state space grids (Lewis et al., 1999; Hollenstein 2013, 2015), which provide a method of visualizing temporal patterns of interaction in dynamic systems such as student-teacher interactions. Specifically, they allow the mapping of two constructs on a grid to visualize interactions between sets of measured behaviors over time. For example, in a classroom where a teacher is trying a new strategy, state space grids help to visualize whether that strategy becomes the norm over time, whether student engagement changes as a result, and whether these paired behaviors and/or responses become a new attractor state or whether after a few attempts the teacher returns to the original/default positioning on the grid. By understanding patterns of adoption of new practices through visualizations, key behaviors or efforts that help change behaviors or interactions can be identified. Prior applications of this method can be found in a variety of studies relating to parent-child interaction (Cerezo et al., 2017), emotional regulation (Hollenstein, 2015), and teacher-student interactions (Pennings, et al. 2014a, 2014b; Turner et al., 2014).

To answer Research Question 3 and understand the relation between the CRT magnitude codes and students' reports of engagement, I mapped CRT magnitude coding against student self-reports of each of the forms of engagement identified in Table 4. Because of the possibility that particular strategies correlated with particular forms of engagement as noted previously, I considered each form of engagement separately. I began by looking at all students to identify patterns across all four teachers in the study and to ensure that the data was able to show class periods showing all five levels of cultural responsiveness.

To specifically answer Research Question 4, I used group-level analysis, examining the relation between practices and responses for male versus female students and white versus nonwhite students. Recognizing that grouping all minoritized groups into a single category is limiting, I further examined individual student trajectories, trying to capture progression over time. From the many individual student stories portrayed by the data, I selected three that I felt displayed distinct patterns of engagement for further discussion. In all cases where grids were used for analysis, I examined data representations holistically for patterns over time as well as comparing measures of dispersion and entropy. Dispersion indicates the range of cells visited in the grid; entropy indicates the number of transitions between grids. Both are a reflection of the degree of movement/variation in the state space. This assisted me in determining whether patterns of teacher behavior and discourse were more effective for students who are historically marginalized in science classrooms.

Trustworthiness and data triangulation

During qualitative coding and analysis of data, I contextualized my observations, memos, and qualitative codes by continually revisiting curricular materials, lesson plans, and researcher feedback documents. In this way, I was able to compare my own observations and codes with other observations and materials. To increase the trustworthiness of observations, I employed several forms of triangulation as defined by Stahl and King (2020). First, use of examples in the coding scheme from several distinct but theoretically aligned frameworks provided theoretical triangulation of the constructs being mapped. Second, by using videos, transcripts, and research group summaries throughout the process of coding, I attempted to triangulate data. Due to the timing of the data analysis (conducted more than two years after the initial classroom videos were recorded) and the possibility of reintroducing sensitive early anecdotes to a teacher group actively trying to evolve their practice over time, it was not feasible to use the teachers themselves for member checking of data. However, a second researcher familiar with the videos and theoretical frameworks reviewed the cases and offered feedback and questions to ensure credibility of the case descriptions. Throughout the process, I also discussed my observations with my advisor, who was one of the PIs on the broader research project and familiar with the pedagogical practices of the four case study teachers.

CHAPTER 4: RESULTS

The following chapter describes both teachers' practice in motivationally supportive classes and students' experiences of those lessons in terms of three forms of engagement: cognitive, affective, and behavioral. Practices are described for the four teachers in the study as four separate cases consisting of qualitative codes and descriptive summaries for each teacher, with each teacher's case being generated from four class periods across the same unit. Student experiences are catalogued through end of class reports (ECRs) taken on the day that classes were filmed so that a side-by-side comparison can be made between teacher strategy use and student engagement.

All four teachers in the study taught lessons developed around the same performance expectations (standards), with a primary focus on the properties of substances before and after the substances interact and determination of whether a chemical change has occurred (MS-PS1-2; NGSS Lead States, 2013). However, the curricula, classrooms, and practices across cases varied greatly, as did student demographics. As such, the classroom vignettes and strategies presented here are far from a comprehensive picture of teaching NGSS as it exists across the United States. However, they provide a window into the kinds of supports provided by teachers who are working to integrate NGSS and supports for student motivation.

Teachers' instructional practices in relation to culturally supportive teaching

The qualitative case studies aid in answering the first two research questions in the study. Specifically, Research Question 1 asks: What patterns/themes relating to culturally relevant pedagogies exist in teachers' planning, strategy use, and discourse while implementing NGSS in classrooms where teachers are attempting to enact motivationally supportive instruction? Research Question 2 asks: What patterns/themes exist in teachers' planning, strategy use, and discourse that lack alignment to culturally relevant pedagogies and may undermine cultural responsiveness? The qualitative cases capture teachers' practice in motivationally supportive classrooms across the course of a chemistry unit, with the aim of describing the range of strategies used that may alternately support and undermine student engagement. Throughout the study, I relied on the coding scheme presented in Table 4 to describe and categorize teacher behaviors. Specifically, I looked for supporting or undermining behaviors in the following conceptual categories: positioning students as knowledge generators; eliciting, valuing, and leveraging of student funds-of-knowledge (FOK); encouraging use and sharing of student language; valuing students' lived experience as evidence; promoting use of students' critical lens to solve problems; and exhibitions of belonging or culturally relevant caring. In the following sections, I begin by presenting a synthesis of the key strategies the teachers in the study used in relation to culturally relevant pedagogy across these six areas. I then present individual qualitative cases for each teacher. Accordingly, the following sections provide both general observations about the type of strategies used as well as specific vignettes from each classroom to provide further detail and examples of practices used by each teacher. Table 5 shows a summary of the videos included in the study. Note that the overall coding for each video instance reflects consistency and variety of teachers' use of culturally responsive teaching strategies as noted in the coding scheme, not their instructional effectiveness or measures of student performance.

General observations

A summary of the key strategies across all four teachers, organized according to the categories expected based on the literature, can be found in Table 6. Overall, my *a priori* coding scheme developed from literature on motivation, science education research, and cultural responsiveness effectively captured teachers' behaviors during qualitative coding, and no additional top-level codes were needed to describe the data. All teachers provided students the opportunity to generate knowledge and valued students' experiences as evidence through strategies such as facilitation of sensemaking conversations and encouraging students to ask questions, generate and track ideas, and allowing autonomy over some procedures. Similarly, codes indicated that teachers valued students' experiences as evidence and encouraged use of student language during discussion by attributing ideas to students and assisting students in making connections between chemistry content and their lives outside of school. It is noteworthy that these codes were most frequently used for passages where teachers supported students in learning about universally-accessible phenomena. Conversely, codes that required a deeper understanding of students' home cultures, such as drawing on culturally situated FOK or using a critical lens to solve problems, were used less frequently. Teachers had differing management styles which allowed me to capture a wide variety of behaviors in relation to exhibitions of culturally relevant caring and provision of belonging support for students.

There was only one type of teacher behavior that was not explicitly described through examples from prior research. Specifically, Caroline continually made routines, procedures, and resources explicit to students, as described in greater detail in the case study. Based on the theoretical framework, I coded this as an example of belonging support, because it made transparent the processes, knowledge, and norms required for being a successful student and was closely aligned to Calabrese Barton and Tan's (2020) assertion that culturally responsive teaching addresses the values and goals of the educational system. A fuller description of the key codes across teachers follows.

Across the case studies, the two codes that were used the most frequently across classes (both as a supporting and undermining) were teachers positioning students as knowledge generators and teachers supporting belonging or exhibiting culturally relevant caring. The prevalence of the first code is perhaps unsurprising given the emphasis on sensemaking in NGSS and the alignment between knowledge generation and the practice of sensemaking. This language illustrates a shift in NGSS from students' "learning about" content and towards sensemaking and "figuring out" science ideas (Schwarz et al., 2017). In fact, both sets of curricular materials used by teachers in the study specifically supported teachers in asking questions like, "What do you wonder?" and "What do you want to know?" or to engage in creating and revising their own mental models. As examples, Sandra used a driving question board to keep track of students' thinking over the course of the unit, while Caroline referred to the unit phenomenon in her teaching, and Steve referred to the unit essential question to keep track of classroom progress over the course of the unit.

On the other hand, the scripted nature of the curriculum (and/or teachers' strict adherence to the sequence of instructional activities) sometimes impeded students' work as knowledge generators as the essential questions and outcomes of many of the activities were predetermined. In some cases, the transition between one activity and another as outlined in the curriculum seemed to disrupt the flow of students' knowledge generation given that work was framed as the sequential completion of all the tasks in the workbook. In other cases, however, teachers used the text as a loose framework that provided the guiding questions and allowed students more liberty to design and test their own procedures and to develop progressively more complex understandings of content through rich discussion and examples. In these instances, this was a practice that teachers engaged in independently to support students as knowledge generators and was not at the direction of the curricular resources.

Belonging was the other most frequently used code, both as a supporting and undermining behavior. Supports for student belonging were not addressed in the curricular materials explicitly but seemed to be something that teachers either supported or undermined organically depending on their teaching styles and relationships with students. This is perhaps unsurprising given that belonging was not explicitly present in the framework for equity pedagogies in science teaching proposed by Kolonich et al. (2011), which is more directly aligned with the NGSS standards than the other theoretical frameworks leveraged to generate the qualitative coding scheme. Teachers exhibited culturally relevant caring through greeting students, use of inclusive norms and classroom routines, modeling positive self-talk, and by acknowledging a range of aspirations and talents. Teachers also frequently incorporated discussion of school events in their classroom discussions as a way of building community and acknowledging students' realities outside of learning science. For example, in one class, Caroline acknowledged a student for helping a classmate dealing with an injury and in another provided an academically inclusive view of what students might accomplish at different kind of high schools after a magnet school visit. Amanda was able to talk about how an upcoming field trip related to students' backyards and how it applied to various science content. However, even in classes that were coded as high due to the frequency of belonging supports did not include explicit discussion of equity, access, or social justice.

The most frequent way that teachers undermined students' belonging was through behaviors identified by Calabrese Barton and Tan (2019), specifically the idea that student membership in the classroom community was contingent on their ability to follow specific rules, routines, and procedures accurately. Amanda and Steve frequently used controlling language to enforce discipline, referring to students' presence in "my classroom" or describing use of "my materials". The use of demanding or controlling language provides an interesting question for discussion, however, as some teacher behaviors might alternately be interpreted as communicating high academic expectations for students or maintaining strict standards of safety.

Of the remaining codes, encouragement of student language and use of students' experiences as evidence were used to a moderate extent, though notably much of this strategy use was usually situated in universal examples and not culturally-specific ones. For example, Amanda and Caroline kept track of student-generated definitions on poster paper, and all teachers attributed ideas to specific students and validated their contributions to class discussion by repeating their words and descriptions. Sandra and Caroline frequently had students compare notes with one partner before sharing out with the whole class, thereby engaging a greater number of students in each discussion. While the IQWST curriculum used a series of universally accessible lesson level phenomena and the district-created curriculum used a unit phenomenon relevant to life in the American Southwest, neither the curriculum nor the teachers highlighted or acknowledged local or culturally situated applications of the content beyond this basic framework. While Caroline did validate a variety of interests (including Polynesian culture and hula dancing), she did not necessarily address community problems or critique discourses of power. Teachers' responses to the needs of English Language Learners were similarly mixed and did not show a particular valuing of culturally situated ways of knowing.

The codes used least frequently across all four cases were use of students' critical lens to solve problems and leveraging students' funds of knowledge. As with use of students' experience as evidence, many of the references that teachers were able to bring to bear in class discussion were universal and acultural, such as dissolution of salt or sugar in water and discussion of videos or demonstrations that the class had watched together. This is again unsurprising given the emphasis in NGSS on using universally accessible unit- and lesson-level phenomena, and again highlights a potential shortcoming in the way the standards are written in terms of validating multiple culturally situated ways of knowing. It further illustrates the absence in curricular materials of teaching strategies that leverage culturally specific funds of knowledge or provision of opportunities for students to think critically about problems in their community, using their scientific knowledge to solve problems. Teachers did not necessarily actively undermine students' use of FOK or student attempts at using a critical lens; these opportunities were simply absent in the classes observed. In fact, students across all four classes engaged in a great deal of critical thinking, to include both inductive and deductive reasoning, categorizing, synthesizing observations, and writing about scientific claims. However, even in cases where the content of the unit was used to understand local phenomena, there was little to no evidence that students sought alternative perspectives and viewpoints or came to anything other than a predetermined response to a driving question.

The sections that follow provide a richer/more granular exploration of the practices in each teacher's classroom, as well as a justification for the overall coding in each lesson.

Caroline

Caroline is a white female, with a bachelor's degree in education and master's degree in education, reading, and literacy. She has 23 years of teaching experience. In addition to teaching 7th grade science, she has experience teaching kindergarten and second grade. Caroline's instructional goals include inspiring her students, strengthening her own knowledge of NGSS and 3-dimensional learning, and to improve student learning by increasing their engagement through a diverse assortment of learning tools. She sees use of motivationally supportive teaching strategies as important in reaching those goals, frequently asks students for feedback about her teaching, and takes pride in developing rapport with her students. The lessons selected from her unit on chemistry take place between August and early October.

In Caroline's school, about 47% of students identified as non-white and 2.5% are English Language Learners (ELLs). Her lab tables are pushed together end to end into three long rows spanning the room, with two students sitting per table, each table facing another table, and so on down the row. During class, she walks up and down the rows to facilitate conversation or stands near her desk at the front of the room near the smartboard and her demonstration table. Her lesson plans draw from a district-created curriculum using a 5E approach (see Bybee et al., 2006) with supplemental resources from Model Teaching (2019) on how to write using the Claim-Evidence-Reasoning framework. The curriculum is specifically meant to support teachers in enacting NGSS. Caroline's lesson plans further show explicit planning for student choice and the opportunity to explain their thinking, as well as opportunities to revise and validate their ideas. The unit of study is based on a driving question about endothermic and exothermic reactions:

> "Students have been introduced to the company Sunshiny Day, who has been tasked to safely move any desert tortoise eggs they find while installing new solar fields. This creates a problem/phenomena [sic] for students to figure out how to help this company create a portable device using chemical reactions to keep the eggs warm." [Lesson plan, August 27, 2019].

In the unit, students begin by developing a shared vocabulary for atoms, elements, and molecules, identify physical and chemical properties, an discuss characteristics of a chemical change. Based on this knowledge, the unit cultivates in a project where students use what they know of chemical change to design a device that uses an exothermic reaction that can be used to transport the eggs. This unit phenomenon is a part of the district-created curriculum but is potentially relevant to students based on their local climate.

Table 7 shows a summary of the four lessons selected from across Caroline's unit on chemical change. For each lesson, the table summarizes the key findings from qualitative coding and provides an "overall" code made based on the breadth and frequency of identified codes. Generally speaking, across classes Caroline consistently uses supports for belonging, values students' experiences as evidence, positions students as knowledge generators, and occasionally elicits students' FOK. At the same time, in some sensemaking episodes, she occasionally undermines belonging or fails to leverage students' FOK or language. Further discussion of key instructional strategies in each lesson follows.

The framework element that Caroline uses most consistently in her classroom is support of student belonging. She routinely calls on students by name as they enter her room, teaches them to be responsible for shared learning, and makes transparent the learning strategies that students need to be successful as scientists. Throughout her lessons she gets to know her students personally, often referencing the jobs and interests of colleagues and former students or asking about and acknowledging student interests outside the classroom including sports, music, and extracurricular clubs such as theater and dance. She shows a strong awareness of students' successes and interests outside of science class in the way she greets and welcomes students to her classroom.

The belonging supports that Caroline uses include almost all the kinds of support identified in the preliminary coding scheme. First, she welcomes and calls on students by name and positions them clearly as members of a team working together. Across instructional episodes, she often says "welcome back" to each student by name, telling them to "come on in", and employs relevant humor in her daily science warmups as students get settled. When students sit down, she asks them to check in to see whether all their teammates are present and ready for the day's learning and checks in with students who have been absent. This is evident from the beginning of the cases:

> "Team one. Are you missing anybody today? Team two. Are we missing anybody from your team today? [Student A]. Thank you. Team three, are we missing anybody from your team today? [Student B]. Thank you." (Lesson 1)

> "[Student A] since you were absent from the lab, you're going to have to be dependent on the people—on your elbow partners to help you through what we're doing today." (Lesson 3)

Second, Caroline makes classroom routines and procedures explicit so that students know how best to contribute to the work of their groups. During lab, she identifies jobs for each person in the group. She also often asks students to make lists of resources that are available to them (the text, a periodic table, their notes, their computers) when they learn about new content, asks them to create lists of lab materials they will need to be successful in lab, or asks them to identify where resources are that they could use to help an absent classmate or to revisit content from the day's lesson. She also ensures that students know their role within the group when they work collaboratively. In the second lesson during a lab on chemical change, she identifies that one student should be getting, measuring, and using water, one person oversees labeling the baggies for each trial of their experiment, one person should oversee safety and goggles, and one person maintains their lab tray. She often supports students in developing roles in class by posing questions or making comments that highlight successful behaviors. For example, she might ask students to identify what tools they can use to help a classmate who is absent, or identifies useful behaviors and strategies that she is observing so that other students can know what kinds of strategies may also serve them as they work towards their shared goals:

> "I'm seeing people that are highlighting. I see people that are annotating taking notes in the margin. So that's telling me that some of you are obviously having some aha moments." (Lesson 1)

As a third strategy for belonging support, Caroline uses language and strategies that promote teamwork and collaboration and frames learning as progress towards shared or community goals. After posing questions or asking students to summarize their learning, she frequently asks students to "put your heads together," "lean in," or "work hard with your elbow partner", explaining that students must help one another to be successful. She also periodically pauses instruction to be sure that students are all on the same page by asking them to identify common vocabulary and shared understandings, and to take turns so that everyone has a chance to contribute to discussion.

Fourth, Caroline models positive self-talk and addresses the fact that sometimes science can be hard but that students should persevere:

> "Is that what science is about? Is science challenging? Yes. Is science tedious? Could science be frustrating? But if we don't persist and we don't have challenges are we ever going to grow as scientists? No, no, no. So that's my goal. I could stand up here and I could have lectured and I could have said, okay, turn to page 1, 2, and let me define what an outcome is for you today. I could bore you to tears, or I could challenge you to build your background knowledge even more on the subject, maybe frustrate you just a little bit, but I promise you that frustration will go away and if it doesn't, I'm here to help you figure out how to make that frustration go away." (Lesson 1)

In framing learning in terms of progress and growth, and validating students' feelings of frustration, Caroline also positions students as knowledge generators and scientists, giving them the opportunity to figure out how to solve problems independently rather than simply relying on her as the source of all information in the classroom.

In the fourth and final class, Caroline takes time away from her regularly scheduled lesson to address students' recent experience learning about magnet schools and discuss and validate a variety of career goals. She both highlights the diversity of careers in the sciences (e.g. EMT, nursing, marine biology) and validates interests outside of science fields (dance, music, art).

These varying supports for student belonging are particularly apparent in the first two lessons when Caroline is trying to establish terms and concepts that students will evaluate later in the unit. In these first two classes Caroline uses the widest variety of strategies, and her commentary continues throughout the entire class session as she highlights strategies over the course of the class period. In the third and fourth class periods, these supports are present, though to a lesser extent, and in the fourth class period a large portion of class is given over to discussing the many opportunities available to students as they move on to high school and a variety of careers.

Caroline's use of a driving phenomenon across units of study also helps support multiple framework elements. For example, she frequently supports use of student language and encourages students to generate knowledge in their groups using their own words. She often has students generate lists or concepts together, identifies one student to be a scribe for the class, then combines individual groups' ideas to come up with a class list, discussing areas of agreement as the group comes to consensus on big ideas. She then references these lists or concepts in students' words in subsequent class periods so that students are continually building on their ideas as their learning progresses. She uses several methods to leverage students' voices. Sometimes she asks students to explain their thinking, or to listen to one another's voices. Other times, she calls out student ideas herself, looking back to anchor charts from previous lessons and citing their previous work, or making connections between current and previous learning:

> "And that kind of lends its way to us solving our problem, our driving question: What kind of chemical reaction are we going to be able to use to keep our desert tortoise eggs warm? We know we're on the hunt to find something that we could mix together to keep it… how warm?"

> “Why would that be helpful to us to make sure we’re all on board with relatively the same definition for each one of these terms?... [Student: Using it when we are discussing different chemicals we’re using to keep the tortoise eggs warm]. Ooh, when we go back to our driving question. I love it. Okay, so I’m ready to hear what you have to give [for this task].”

Further framework elements that Caroline uses primarily during sensemaking episodes are using students’ experience as evidence and leveraging their FOK, assisting them in connecting concepts and experiences outside the science classroom to their in-class learning. For example, she uses her daily warmups to encourage students to make connections between their science learning and observations they have made outside of class:

> **Caroline:** Shifting gears back to our daily science starter, what are examples of a temperature change, what evidence do you know that a temperature change occurred? Thank you for leading us off, go for it.
> **Student A:** When you turn on an oven, your food gets cooked.
> **Caroline**: Ok, when you turn on an oven, obviously something has to happen for our food to be cooked… ok, what else?
> **Student B:** When ice in your cup melts it’s the water getting…

There were a few clusters of undermining behavior across Caroline’s classes, or instances of mixed coding in a single sensemaking conversation. In several cases, students share ideas and Caroline asks, “Does anybody disagree with [Student A]?" during whole group discussion, which potentially shuts down the thinking of the student who has just contributed to discussion without offering them the chance to explain their thinking. However, some of these references were dual coded as an instance of positively promoting use of students’ critical lens to solve problems. The initial coding scheme included the opportunity to develop critical lens through evaluation and critique of student ideas, and the need to seek and validate alternative perspectives and viewpoints as examples of positive supports. Caroline frequently asks her students to raise their hands if they agree or disagree with a statement, invites them to explain why they disagree. By frequently incorporating opportunities for students to comment on one another's ideas, the potential negative impact of inviting disagreement is potentially lessened.

Similarly, during the second lesson, Caroline failed to support or leverage students' use of FOK during a sensemaking discussion about physical and chemical change. The class was attempting to make a shared list of indications or signs that a chemical change occurred. They had designated a class scribe and had already listed gas production as a sign of chemical change, but they struggled with whether a color change should go on the list:

> **Caroline:** Last year, I know in 6th grade you guys talked a lot about physical changes, and understanding physical changes, so I know you know what those physical changes are. So physically I can change my appearance by cutting my hair. But is my hair still hair?
> **[Students]:** Yeah.
> Caroline: Yeah, I just made my hair shorter. But if I went to the beauty parlor and decided to get highlights in my hair, is that just a physical change do you think?
> **[Students]:** (Chorus with both 'yeah' and 'no'.)
> **[Student A]:** (audibly) Yeah.
> **Caroline:** Yeah? Who wants to disagree with [Student A]? It is a physical change, right? Because my hair is gonna change, but how else is my hair changing if I get highlights in it? I'm changing the… what?
> **[Student B]:** Color?
> Caroline: Color. Would you guys say yes or no to a color change… being an example?
> **[Students]:** Yeah
> **Caroline:** Who agrees with color… color change… a prominent color change means a chemical reaction? (Some but not all students raise hands.) I see some yeas and some nays. [Student C] can you give me why? Because we have gas production [on the board]. You're saying color change is one, so let's put color change. All right.
> **[Student C]:** Because, um… the, um, because if you have like the chemical, the chemical that's changing the hair color.
> **Caroline:** Yeah, because remember we were talking about hydrogen peroxide? I'm bleaching out my hair, right? Then I'm adding the chemical in to add the color.

In this discussion, Caroline is trying to get students to identify that color change can be an indication of chemical change. At the outset of the conversation, Caroline asks the question, "Is my hair still hair?" in the context of getting a haircut, which all the students know is an example of physical change, which frames the question aptly in the context of the performance expectation because it indirectly addresses the intrinsic chemical properties of hair and the fact that they do not change when cut. However, students have mixed reactions to the question of whether bleaching and dying hair is an example of a chemical or a physical change. Students likely have experiences where color change is not in fact a sign of chemical change, such as when objects are painted or dyed without altering their chemical composition. This leads to initially mixed responses and a combination of ‘yea’ and ‘nay’ votes in discussion. If students do not have experience with the process of bleaching and dying hair, they may or may not know that hydrogen peroxide can be used as a bleaching agent in order to make connections to their previous work with hydrogen peroxide. Further, they may not know that hydrogen peroxide causes hair to change color because chemical changes occur to organic compounds in the hair that absorb light. It is quite possible that with other probing questions, Caroline could have elicited more conversation about what students know about chemical properties of hair and how it might change when dyed in order to simultaneously leverage some students’ FOK about hair and leave space for further discussion about students’ experiences with other kinds of coloration or dying that is not the result of a chemical change.

Summary

Caroline’s use of culturally responsive strategies includes a variety of belonging supports, support for student language, and opportunities for students to be knowledge generators. There are a few instances of potentially undermining behaviors, including a few brief instances of shutting down of sensemaking, but the environment is generally positive and welcoming and every student has a role in the classroom. Interestingly, although Caroline demonstrated a clear knowledge of her students’ interests outside of class and acknowledged a wide variety of hopes and dreams, in the four videos coded, Caroline did not leverage students’ FOK or outside experience to make sense of chemistry content and relied largely on the accessibility of the unit phenomenon and teaching strategies designed to find consensus to reach her students. Her focus on the classroom routines and structures necessitated the addition of further descriptive text in the "belonging/culturally relevant caring" category outside of the initial examples from the literature, but these supports were often acultural, focusing on the importance of teamwork and the value of student thinking without acknowledgement of community-based or culturally-situated knowledge or concerns. Caroline's seamless integration of community building into the classroom is perhaps unsurprising given her background in elementary education, and the lack of cultural context or frames of reference in the supports is also unsurprising given the way the chemistry standards are written in NGSS. This omission of cultural context is therefore as much an artifact of the standards themselves as a missed opportunity in classroom planning.

Based on these observations and descriptions of teacher behavior, the codes assigned to Caroline's four classes were high, medium-high, medium, and medium-high, respectively (see Table 7). The first class contained consistent use of tools from across the coding scheme throughout the entire class period, including frequent belonging supports in how she welcomed students, encouraged them to work together, and emphasized the importance of generating shared language. In the second class session, Caroline used many of the same supports with nearly the same frequency, but this instructional episode also included some shutting down of sensemaking and potential undermining of student language. However, these instances were dual coded in several cases as an opportunity to share and critique ideas; because Caroline's offers for students to disagree with one another were done without sarcasm or explicit negative commentary about students' ideas, the class was coded as medium-high. The third class was coded as medium both because the breadth and frequency of supports was not as high as the first two classes, and because of the brief instances of controlling language. Finally, the fourth lesson was coded as medium-high. While the codes in this class period centered primarily on Caroline's discussion of high schools and STEM careers—and therefore the variety of codes is less than in some of the other classes—her inclusive language and acknowledgment of a variety of aspirations after middle school shows strong evidence of culturally relevant caring. However, the relative absence of other strategies as well as a single episode in which Caroline potentially shuts down sensemaking prevented the class period kept the class period from being coded as 'high'.

Amanda

Amanda is a white female with a bachelor's degree in geology and a master's degree in secondary education with a science focus. She has 13 years of teaching experience, 6 of which were as a full-time classroom teacher and an additional 7 as a licensed substitute in the same district including 7th and 8th grade science as well as 6th, 7th, and 8th grade math as a long-term substitute. Amanda's instructional goals include "implementing high quality science instruction techniques to create better, more NGSS-aligned curriculum [sic]", and "implementing strategies that help [her] demonstrate student growth".

Amanda's classroom is stadium/lecture hall style in the American southwest with a culturally diverse group of students (90% non-white; 26% ELL). The teacher desk, audiovisual materials, and many resources are at the bottom of the room, with levels with student seating leading up and away from the teacher desk towards the room exit. On each tier of the student portion of the room, lab tables are arranged facing the teacher desk so that students can work with a partner. Amanda spends most of class at the bottom/lecturer area of the classroom, circulating when students are doing lab or independent work, though it is difficult for her to move throughout the room during whole class discussion because her teacher resources (projector, etc.) are all at the bottom level with students arranged around the outside. Amanda is using the same district-created curriculum and the same unit phenomenon as Caroline. As a part of her planning process and her communication with the research team during her unit of study, Amanda's lesson plans include annotations on her resource packet for places where she can support student belonging and feelings of competence. She identifies instructional strategies in her notes, showing intentional use of groups and partners to help students feel more comfortable in developing new ideas, provision of scaffolding student responses through sentence stems, and explicit places where students can use past learning or past resources to make them feel competent. The lessons selected from her chemistry unit cover the time period between August and early October.

A summary of the key codes for Amanda's four classes can be seen in Table 8. Amanda's classroom is interesting in that the primary supporting and undermining behaviors observed across lessons both fall into the coding category of positioning students as knowledge generators, with similarly mixed codes for supporting and undermining belonging. On the one hand, Amanda frequently encourages students to generate and evaluate ideas, develop explanations, and engage in sensemaking. For example, at the outset of Amanda's unit on chemical change (Lesson 1), she asks "What do you think is important? What do we still need to know? What do we still need to know to figure out our problem? What are we figuring out right now?" In Lesson 1, Amanda models "I used to think this, but now I know this. Look how far I've come." In Lesson 2, students have observed a series of chemical reactions and are using inductive reasoning to come up with a list of characteristics that might typify chemical change. Amanda consistently insists that their perspectives and observations are unique to them, and that their thoughts are key to meeting this goal:

"You're the only one that can see [your questions]. You're the only one who knows what you noticed, what you wonder about or what you think. I can't give you those answers. They have to come from you" (Lesson 2).

Amanda also offers students the opportunity to catalogue their learning and use their observations to draw conclusions. For example, in Lesson 4, she explains, "Today we are going to do what scientists do and make observations. We're going to be making observations about the properties of different substances. So today it's going to be really important that when we're describing these properties, we try to use scientific terms. So instead of saying something is... oh, I don't know, sandy, we could say that maybe it's fine grained, we could talk about grain sizes." Some of these questions and instructional scaffolds are embedded in her curriculum, but Amanda also organically puts students in charge of their own learning by giving them the opportunity to make small procedural decisions about how to execute lab procedures, and frequently reminds them that part of learning is keeping track of their thinking across the course of the unit. In doing so she illustrates a strong content background and a familiarity with multiple ways of identifying and representing key ideas across a variety of phenomena.

As an example, in lesson 2, Amanda asks students to identify signs of a chemical reaction, drawing on their observations to generate a list:

> **Amanda:** We're looking at things before and after something happens to determine if that 'something' was a chemical reaction. And one of the things that we're looking for is… what? What are we looking for?
> **[Student A]:** Patterns.
> **Amanda:** Thank you. Patterns. We're going to be looking for patterns. So… in the chemical reactions that we watched, did you notice any patterns? Were there any things that, anything you that saw that really screamed out, hey, that's a chemical reaction? [Student A].
> **[Student B]:** Every time something got mixed, something would happen.
> **Amanda:** Ok, so every time something got mixed, something would happen. No, that's good. Because if nothing happened, then it probably wasn't a chemical reaction, right? … [Now the class is] going to be answering this question: which patterns did you see in your

observations that might be signs that a chemical reaction is occurring? So… something really changed, what else? How did things change?
[Student C]: Change in color.
Amanda: Change in color. What else?
[Student D]: A different size than it was before?
Amanda: Ok, so something really changed size. Um… ok what—what happened with the elephant toothpaste?
[*Various students murmuring answers*]
[Student E]: Ooh!
[Student C]: It exploded.
[Student B]: It blows up
[Student F]: An explosion!
[Amanda]: But why?
[Student D]: Because you added soap.
Amanda: There was soap in there. We added soap. Why do you think the soap—
[Student B]: So it could be foamy.
Amanda: So it could be foamy. So it was making soap bubbles, but why was it making bubbles?
Student B: Because it was a chemical reaction.
Amanda: Because chemical reaction, keep going…
Student B: A chemical reaction was like…
Student C: Hydrogen, um… peroxide?
Amanda: What was in the bubbles?
Student: It was about dry water, or dry water or dry something?
Amanda: A gas. So there was a gas in the bubbles. That's why we used the soap, so we could see that gas being released. Um that's what was making the bubbles was there was a gas being released. Do you think that's a sign of a chemical reaction? If there wasn't a gas and all of a sudden there is one, so bubbles could be a good sign that a chemical reaction was occurring?

In lesson 3, students divide themselves into groups to test one of up to 8 different possible combinations of calcium chloride, sodium bicarbonate, water, and phenol red (an indicator). Using their list of potential sources of evidence, students will determine whether a chemical reaction has occurred in each combination. During the lab, Amanda circulates, prompting them to "Talk to your group about how you're going to design this experiment, how you're going to figure out if your ingredients make a temperature change or color change or produce a gas." Later in the lesson, anticipating that students may not be able to directly observe gas production, she asks, "If a gas is produced, how are we going to know?" and helps them think through the experimental procedures they are going to use. At the conclusion, she encourages students who did not have a positive result:

> **Amanda:** How did it go?
> **[Student]:** We failed.
> **Amanda:** No, you didn’t fail. Did you gather data?
> **[Student]:** Yes.
> **Amanda:** Okay, so what happened?
> **[Student]:** No color, no gas.
> **Amanda:** Good, so you eliminated that as an option. So you did do something, even if you didn’t have a reaction.

In each of these cases, Amanda is trying to encourage students to generate knowledge, work together, and document their ideas, supporting their position as knowledge generators in the class. These instructional moves provide evidence of culturally responsive teaching particularly in the area of knowledge generation in that they validate the unique perspectives and thinking of each student and allowing them the autonomy to make decisions about how to do an activity. Amanda’s content knowledge is visible here as she clearly knows how to anticipate questions or challenges and help students navigate through portions of class that may be more difficult.

In facilitating discussion, Amanda frequently draws on anecdotes and lesson level phenomena to support students in knowledge generation and in doing so provides students with the experiences necessary to make sense of content. Like Caroline, Amanda leverages a variety of materials to help her students access content. Her lesson plans show her integrating videos, a website called the Molecularium (Rensselaer Polytechnic Institute, 2023), PhET simulations (University of Colorado Boulder, 2023), and different representations of atoms and molecules. She explicitly discusses the scale of chemical reactions, allowing students to choose from multiple representations, addressing the CCC of scale and proportion. By drawing on a diverse array of examples that illustrate concepts, she creates experiences that students can use as evidence to assist them in making sense of science concepts. Examples she interweaves anecdotally are scientifically relevant, such as the Wicked Witch melting, jumping into a pool, mixing salt or sugar and water, or examples from videos in cases where students may not have personal experience with a particular phenomenon. Amanda's knowledge of the content and a variety of experiences that students have access to enable them to connect science content to things that occur outside the science classroom. However, she falls short of inviting culturally situated funds of knowledge (FOK) as examples, relying primarily on examples that she considered universal.

A further category of supporting behavior that Amanda uses in her classroom is use of student language. Amanda keeps track of class definitions and student language using chart paper so that students' learning is framed in terms of their own observations and explanations. Amanda enforces the value of these observations by referring to students' answers from previous class periods. For example, when looking back at work from a previous class, Amanda "These are some of the things that you got together and wrote down… You said elements are made of atoms; the smallest unit of the chemical element." In debriefing their observations, she asks for students to identify common themes and come to a consensus, asking questions like "Are we ok with this definition? Do we need to change it at all?" (Lesson 1). When she facilitates discussion in lesson 4, she repeats ideas that students have contributed and highlights strong use of scientific terminology in class discussion.

Despite this frequent support for student knowledge generation and use of student language and ideas across the unit, in many instances, Amanda frames student learning as a need to complete student work packets and many instructional instances are dual coded as undermining students as knowledge generators because of the need for students to follow a predetermined instructional sequence. In Lesson 1, after prompting students to identify what they need in order to think effectively about their unit problem, Amanda almost immediately switches to the need to fill out packets completely as evidence for learning:

> "Quite a while ago, you were supposed to have the first page filled out. So now we're… today we're working on the third page, which isn't to say that you still don't have time to go back and fill that [earlier page] out…" (Lesson 1)

In this way, being successful in class is often framed as completing packets and complying with predetermined classroom procedures.

Throughout instruction, Amanda uses a variety of supports for student belonging. She greets and calls on students by name, continually reinforces that students are acting as scientists, and validates the difficulty of procedures, creating a culture where it is ok to make mistakes and revise ideas across the course of the unit. Occasionally, Amanda also undermines student belonging when she enforces strict behavioral compliance and invokes rules or teacher power as a reason for doing things rather than classroom activities being used to help reach shared learning goals. For example, in the first lesson, Amanda gives the students choice in terms of where to sit, but ends up spending several minutes discussion the conditions associated with that choice:

> **Amanda**: I'm going to give you an opportunity to choose where you sit today, but with that power of choice comes responsibility. And right now, you're not living up to that. Cause what you're going to have to do is, if you choose your seat, one, you're going to have to choose wisely. You're going to have to pick a place where you are not um disrupting the class. You're not—you need to pick a place where you're not going to be constantly talking to the person next to you… When I tell you to, you can take your packet, um, a folder if you need something to write on, or you can grab one of the books in the back of the room as long as it gets back to where it belongs, and you guys can come join me in this general vicinity. Ok? So, paper, pencil, something hard to write on. Go now. Find someplace so you can stay right where you are if you want or you can sit on the steps or you can sit here in front as long as you can see the board.
> You have 90 seconds, let's go clock is ticking."
> **Student A:** How will we know when time is up?
> **Amanda:** It doesn't matter. I'll tell you when your time is up.

[Students spend several minutes moving]
Amanda: No.
Student: [Inaudible]
Amanda: Absolutely not.
Student: I can't sit back here?
Amanda: The point is getting everybody involved. You sitting in the back of the room is not you being involved. (Lesson 1)

Similarly, in the fourth lesson on using scientific properties to categorize or describe substances, Amanda has clearly planned a variety of scaffolds to support student learning, and begins by framing class as an opportunity to think like scientists, but the flow of conversation is disrupted by several students who are not participating. Student A, a Black male, is sitting by himself, apparently because of poor behavior in previous classes:

Student A: I need a partner!
Amanda: No you don't. You need to work.
Student A: Well I want a partner!
Amanda: [Student A]...
Student B: Your partner's Casper [the ghost]
Student A (to Student B): Why are you so fat?
Amanda: [Student A]...
Student A: Yes?
Amanda: This is why you're not working with a partner.
Student A: Why?
Amanda: Because you can't behave appropriately.
Student A: I can behave appropriately. I don't care. Well he just said my partner's Casper [the ghost], so I said why are you so fat? (inaudible)
Amanda: Exactly. This is why you're working by yourself.

In the remainder of class, Student A continues to engage in off task behaviors. At one point, Amanda pulls him into the hall and tells him that he does not have a partner because he is not behaving. When he returns to the classroom, she ignores his disruptive behaviors and a special education coteacher works with him individually for the remainder of class.

In this last class in particular, Amanda is attempting to support students in thinking like scientists, but progress is periodically derailed due to student misbehaviors. In some cases, Amanda addresses behaviors directly and publicly; in other instances, she speaks with students individually; in still others, she ignores misbehavior. In some cases, Amanda's actions may be seen as undermining, because she relies on traditional rules about appropriate energy and volume and enforces them using controlling language. However, she also occasionally frames her decisions in terms of protecting other students' learning and caring for equipment. In the 4th lesson, she has to get rid of a hand magnifying lens that has been intentionally scratched and rendered useless by a student, and comments:

> "The lens is dirty. No, it's not dirty. It is scratched. And somebody did this intentionally. I mean, this was like a concerted effort to really just destroy this tool. Let's not do this, okay? Because now this is totally unusable. Okay? And not just for today, but for classes, for years to come, won't be able to use this (Lesson 4)."

The fourth lesson in the study received a 'low' code for cultural responsiveness due to the overt power struggles between Amanda and one or two misbehaving students. However, these power struggles and disciplinary issues with students provide an interesting opportunity to further explore power dynamics in the classroom and how culturally responsive pedagogies suggest addressing students who are misbehaving, disengaged, or otherwise violating classroom norms.

Summary

Across classes, Amanda uses teaching strategies meant to elicit student ideas, share language, come to consensus, and assists them in making connections between science concepts and outside examples. Her background in the sciences is evident as she responds seamlessly to student examples and relate class content to accessible examples. However, the use of packets as the main structure used to document student thinking undermines students' ability to take control of the learning and participate in sensemaking in their own way. Her classroom is also reliant on traditional teacher/learner roles where the teacher holds the knowledge and students' role is to follow a series of steps until their understanding mirrors the teacher's. Amanda's occasional power struggles with disruptive students also often undermines class progress as she enforces quiet and compliance when faced with a chatty or disruptive student. Because of these observations, Amanda's four class sessions were coded medium low, medium low, medium, and low for cultural responsiveness (see Table 8). The first two classes were similar in that they included evidence of intentional scaffolding to support student thinking and to position students as knowledge generators, but controlling language and negative framing that undermined belonging support. The third class was scored as medium because the prevailing interactions included consistent supports for students' autonomy in doing their lab with relatively fewer undermining behaviors, while the fourth class was scored as low because of the larger number of negative interactions and controlling interactions, again with relatively fewer positive/supporting behaviors.

Sandra

Sandra is a Black female with a bachelor's degree in business and a master's degree in elementary education. She has 15 years of teaching experience including 6th, 7th, and 8th grade science, as well as math, ELA, social studies, and creative writing. Sandra's instructional goal is to incorporate technology into her teaching and increase her own professional knowledge through professional development experiences. Sandra's students sit in groups of four at lab tables throughout her room with groupings around students who are academically stronger and can take a leadership in group discussions. Her desk and a whiteboard where she puts anchor charts and notes are located at the front of the room. During class, she alternates between whole group discussion and small group discussion/lab during which point she walks around the room and helps students. The lessons selected for analysis span the time period between December and early March. While the standards being taught are therefore the same as Caroline and Amanda, the lessons take place later in the school year.

Sandra is using the IQWST curriculum (Krajcik et al., 2011) and the instructional instances in the study are from a unit centered around the question, “How can I make new stuff from old stuff?” The unit takes students through a discussion of definition and properties of matter and through a series of explorations and labs designed to help them understand that the atoms of a substance rearrange during a chemical reaction to form a new substance with distinct properties. The IQWST curriculum is specifically written to support NGSS and incorporates strategies such as unit and lesson level phenomena, use of a driving question board, and a variety of opportunities for students to engage in the SEPs. Throughout the unit, Sandra consistently asks students to observe or explain phenomena such as blowing up a balloon, sand becoming glass, or cake ingredients becoming cake, relying on universally accessible phenomena and examples to help develop students’ understanding. Her curriculum asks students to ponder examples such as straw turning to gold in fairy tales, evaluation of claims on shampoo bottles, and other phenomena, but Sandra also provides her own examples and opportunities for students to discuss their ideas. While she often uses the suggested scaffolding from the curriculum to structure student conversations, Sandra’s planning also incorporates thinking about how she can get students to exercise curiosity and feel confident in their work.

The key supporting and undermining behaviors for Sandra can be found in Table 9. The most frequently used supporting behaviors across Sandra’s classes include positioning students as knowledge generators, supporting their belonging, and valuing their experience as evidence. Throughout her lessons she attributes ideas to students and provides students autonomy over their learning by creating a community of shared scholarship. Sandra is new to the IQWST curriculum, however, and perhaps as a result sometimes the connection between parts of a lesson are not clear in terms of sequentially building student understanding. The most frequently coded undermining behavior in Sandra's classroom is also positioning students as knowledge generators because she occasionally relies on curricular packets to frame and document learning without helping students make connections between their ideas and the tasks in the packets.

Across all class periods, Sandra consistently provides belonging support for her students and helps them identify as scholars and students. At the beginning of each class, she welcomes students by calling them "thinkers," "esteemed students", or "scholars". Like Caroline, Sandra also verbally acknowledges students who have been out, saying "we missed you" or checking in on what they need to do in order to be prepared for the current class. When students are absent, or when opening new class sessions, Sandra asks questions like, "who would like to bring us up to date?" (Lesson 3), She also positions herself as a learner alongside them, creating an opportunity for them to learn together as a classroom community. In the first lesson, she explains that they will be using a new curriculum, and says that, "…just like you, I had to study as well. So we are going to be working together to get through this, and hopefully you will find it enjoyable" (Lesson 1). By creating an atmosphere of shared scholarship, Sandra explicitly names students as equal participants in the learning experience and positions herself as a facilitator who is sharing in the learning experience rather than transmitting information to them.

Sandra's facilitation style also encourages belonging in the way she encourages students to share their thoughts, comment on one another's ideas, and enforces that they need to listen to one another's voices. For example, she frequently pauses in class to ask questions like, "What questions do you have?" (Lesson 3) or asks students to summarize their learning with questions like "Who would like to bring us up to date?", giving clear control to students in terms of capturing their shared thinking or offer commentary on what they are learning. At the end of classes, Sandra offers open-ended opportunities for students to share their thinking through questions like, “Would anyone like to share anything they found exciting about the lab today?” By offering frequent opportunities for students to comment, give feedback, or ask questions, she establishes a classroom environment where students can feel relatedness as a result of shared meaning making. This also places the onus on students to be responsible for summarizing their learning, making connections, and listening to one another’s ideas in order to advance their own thinking.

A second way that Sandra supports students is through creation of opportunities for students to generate knowledge and share their own experiences as evidence. Sandra frequently uses open-ended questions in whole class discussion to provide opportunities to share their experiences as evidence or generate knowledge. For example, in lesson 1:

> **Sandra:** When you use the word ‘stuff’, what are some things that would be examples of stuff?
> **[Student A]:** Uh, clothes?
> **Sandra:** Ok clothes, anyone else?
> **[Student B]:** Toys
> **Sandra:** Toys. Thank you, games… All right, the stuff you are naming, sounds like stuff that we could be calling ‘matter’ in science. What do you know about matter? Who can share with us? What do you know about matter? Yes?
> **[Student C]:** Matter is something that takes up space.”
> **Sandra:** Ok. Anyone else—thank you—anybody want to add anything else to that? Yes?
> **[Student D]:** Matter is all around us?
> **Sandra:** Awesome. Anyone else? Well, we have thinkers here. Yes?
> **[Student E]:** There are different forms of matter.
> **Sandra:** Okay, all right, anyone want to add to that? [Student E] said there are different forms of matter. Would anyone like to add to that? Okay, someone that I have not heard from, because I know we all have our thinking caps on… what if someone said, ‘My little brother spilled stuff all over my homework’, if he had knocked over juice, soda, or milk, is that stuff all still matter?
> **[Students chorus]:** Yes
> **Sandra:** Who would like to elaborate—is that still matter? Okay, I love it that you have your hands up but I would love to hear from someone else.”
> **Student:** Matter has a shape and volume.

Sandra: Ooh, matter has shape and volume. We got some thinkers going on here. All right, so if I were to hold up this glass and ask you, what is this glass made of? What is this glass made of?
[Students chorus]: Glass
[2-3 students]: Sand
[1 student]: Matter
Sandra: What is this glass made of? I heard sand, I heard matter. Okay, okay… what did you say? Who said sand?
[Students raise hands]
Sandra: How does sand become glass? How does sand become glass? [Student F]?
Student F: With heat.
Sandra: Heat, mmm, all right. Sounds like we got some thinkers here. So this unit that we are going to delve into today is a unit about old stuff like sand, the stuff that scientists might start with, and how it becomes new stuff like glass. What other examples do you have of old stuff being made into something new? Old stuff being made into something new. [Student G].
Student G: Trees being made into paper.
Sandra: Oh wow, trees being made into paper. Hmm, we got some thinkers here.

In this vignette, Sandra uses the guiding questions provided in the curriculum to ask a series of questions to elicit students' prior knowledge of the concept of matter and to guide them towards examples of chemical change. In doing so, she includes multiple students' voices in whole class facilitation and builds towards some of the driving questions that they will answer later in the unit.

Sandra's interactions with students during small group work in the same class period similarly illustrate the way she situates herself as a facilitator and places control of learning and thinking in the hands of her students. When students prepare to do lab in Lesson 1, she gives them the procedures in the packet, explaining that they will do the lab then come back to discuss as a whole group. During the activity, she circulates, asking probing questions and facilitating with comments like, "How do you know…" "Where are we now…?" "How are you going to…?" "How would you…" In doing so, she places students as knowledge generators by giving them procedural autonomy over how to direct their actions in class. She encourages them to keep track of their thinking with comments like, "That's a question that hopefully we can answer. So you might want to write that down as a question to find an answer to." She raises the question of mixtures, using air and trail mix as examples, allows students to process, and then moves into progressively more complex understandings of the content. In Lesson 2, students are exploring solubility of materials by systematically combining soap, oil, and water. Sandra provides students the opportunity to figure out how they will complete procedures, circulating and providing them materials, asking them probing questions and providing support. When students make mistakes or express hesitation, she asks them to refer to their procedures, or asks questions that will enable them to compare observations across conditions. In doing so, she strongly supports their position as knowledge generators.

Like Caroline and Amanda, Sandra's interaction with students in small groups focus on asking probing questions. However, Sandra's classroom also illustrates the clearest use of a driving question board and intentional tracking of student-generated questions over the course of the unit as a strategy to position students as knowledge generators. While all of the teachers in the study generated common terms and definitions at the outset of the unit and used classes to build progressively more complex understandings of science ideas, Sandra was the only one to refer back to student-generated questions later in the unit. She uses post-its and a driving question board to have students keep track of their questions as a class and points to shared sensemaking as the way to find the answers to those questions. As she stitches together students' questions and observations, she explains that they will use comparison skills to "paint a story" over the course of a unit as they make sense of observations together. In Lesson 2, Sandra refers to some of the questions they contributed to the driving question board and retires questions they have come to a consensus on. While Caroline refers back to the unit essential question, and all teachers referenced previous ideas and understandings to help frame new learning, Sandra is the only teacher to frame the unit in terms of telling a story.

Across the unit, Sandra gives her students multiple opportunities to think about the ways that the content in the unit relates to their lives outside of school, mentioning baking, Kool Aid, and giving students the opportunity to similarly generate examples of the ways solubility and other science concepts relate to their own experiences. She also helps make connections to other subjects:

> "You talk about products all the time in math: it is the result of multiplying numbers together. The numbers that you are multiplying are like your reactants or your old substances. Once you multiply, you perform the operation and multiply and that number that you end up with is like your product or your new substance. So you've been working with… you've been working with this all the time in math, it's just that. Now in science, same terminology. It's just that now instead of applying it to multiplying numbers or expressions, we are now applying it to elements and chemical formulas." (Lesson 3)

There are a few instances where Sandra's tight alignment to the curriculum—most notably, the need to complete the packets for each unit—undermines students' ability to generate their own knowledge. For example, in Lesson 3, students observed magnesium burning in the presence of oxygen to create magnesium oxide, represented by the equation: $2Mg + O_2 \rightarrow 2MgO$. Sandra then asks them to use marshmallows and toothpicks to represent atoms and the bonds between them, respectively, and to model the chemical reaction on the board. In the class, Sandra has written the chemical equation on the board and walks students through splitting apart the bond between the oxygen atoms and reforming two magnesium oxide molecules. Students follow her instructions, but quickly lose focus. Ostensibly, the curriculum offers students the opportunity to model chemical reactions in multiple ways—both through chemical equations and a physical manipulation of objects—but the framing of the activities makes it seem as though students are jumping from one discrete task on a to do list to another rather than building towards a cumulative understanding. Sandra's facilitation generally helps weave together students' observations, but as in Amanda's class, some transitions and tasks feel more like completing the tasks in the packet are the primary goal of the class and that all tasks must be completed sequentially.

Summary

Sandra's classroom provides many examples of belonging support through positioning students as knowledge generators and explicitly naming them as scholars, thinkers, or esteemed students. Like Caroline, Sandra's greetings to students from the time they come in the door and throughout class activities and discussions emphasizes their importance in the classroom and the value of their perspectives. Sandra utilizes probing questions in the curriculum but clearly welcomes students' experiences and ideas and centers them as a part of shared learning. Sandra's four classes were coded as high, medium, medium low, and medium (see Table 9). Across all four classes, Sandra's facilitation style repeatedly reinforced student belonging and their position as knowledge generators as she enforced that students listen to one another's ideas, generate examples as a part of discussion, and keep track of their ideas across the unit. The first class showed the clearest and most consistent application of a variety of strategies to support student thinking, promote belonging, and leverage student experience. The second and fourth classes similarly showed intentional facilitation of essential questions but had occasional instances where student behavior and framing of learning as completion of packets or complying with class rules showed up as undermining examples. The third class, which was coded as medium low, showed less frequent and less varied supporting evidence, and was different from the other classes in that transitions between activities seemed to be abrupt rather than in response to a need to fill a gap in student learning or thinking.

Steve

Steve is a white male, with a bachelor's degree in chemical engineering and a master's degree in education. He has 23 years of teaching experience including 7th and 8th grade science as well as 8th grade math. Steve's goals are to attain an 85%+ passing rate in his classes and to implement two brand new units. He sees the connection between motivational strategies and his teaching goals, but his primary goals for his students are academic. Steve's teaching experience is exclusively in middle school math and science, and the depth of his content knowledge is clear in his interactions with his students across instructional episodes. His classroom is moderately culturally diverse, with 23% of his students self-reporting as non-white. Like Sandra's classroom, his students are at tables in groups of four, but there is substantially more space in the room between the table groups. Steve is using the same IQWST curriculum as Sandra, and his students have bound copies of the curriculum in books. He uses a TV screen to project a copy of the book or supporting materials in the corner of the room. During class, he annotates on the textbook document with where the students should be looking in their books, writes students' answers to model what they should be filling out, or captures their thinking in writing. When students come into class, he begins with bell work, generally from the book, where students begin their science work for the day by reading a portion of the book, summarizing prior learning, or previewing material for the coming class. He may ask them to read a portion of the book, share out information from it, etc. Like the other teachers, he generally leads whole-class discussion from his desk; he spends more time circulating around the room during lab, group, or individual work. The four lessons selected for analysis and coding took place between mid-January and mid-March; the summary of key strategies used across Steve's four instructional instances can be seen in Table 10.

The primary code for both supporting and undermining students that is apparent in Steve's classroom is in positioning students as knowledge generators through opportunities for sensemaking. While Steve uses the curriculum and the instructions that comes with it, he facilitates a lot of conversation using his own examples and knowledge, seamlessly integrating his examples into completion of the tasks outlined in the book. For example, in Lesson 1 Steve facilitates a lab where students put aluminum foil in copper chloride and compare the properties of both materials before and after they interact. Students have access to the safety rules and procedure and Steve has them read and share out and follow the procedures to the letter, but in discussing the properties of materials before and after they interact, he brings in his own anecdotes, examples, and experiences to contextualize student learning. For example, he encourages students to be precise in the way they make observations, changing qualitative observations like "small" to exact measurements and reminding students to include things like the state of matter of the materials, their texture, color, etc. and walks them through the appropriate technique for smelling materials in lab and obtaining a temperature measurement in Celsius. Like Amanda, he shows strong attention to precision of language as students make observations.

In lessons 2 and 3, Steve helps his students as they struggle to define and calculate density and use the concept of density to explain why some objects sink and others float. The following vignette are typical of Steve's teaching style in that they show his ability to spontaneously draw on examples, clues, and phrases in students' language to guide them towards a "correct" answer, but he also often shuts down incorrect answers with comments like, "No" or "Try again". In doing so he provides mixed support for students as knowledge generators (both supporting and undermining). For example, in Lesson 2, he and his students define density in the context of their examination of two cubes of the same size but different weights. In Lesson 3, (edited for brevity), which takes place a week later, he continues:

> **Steve:** "If you measured the whole bar of soap… if I took the density of an entire bar of soap, would I get the same density as with this (smaller) piece of soap? **…** What does the density actually mean? And we've mentioned it a couple of times. I wanna make sure everyone kind of gets this down too. What does density actually mean?
> **Student A:** How hard it is?
> **Steve:** No that's hardness.
> **Student A:** Oh.
> **Steve:** [Student B]?
> **Student B:** How tightly the molecules are packed together?
> **Steve:** Depends on two things, it's kind of the same thing as mass and volume. It's how tight the molecules are packed together, and the size of the molecules, some molecules are… some atoms are bigger than others. Okay. And how tightly they're together, if it's the same stuff. Are the molecules [in the soap] packed the same?
> **Students:** Yeah
> **Steve:** So that's basically [question number] two… is the density different with those two bars or pieces of soap?
> **Students:** No.
> **…**
> **Steve:** How many of you have been to the ocean? … Ocean is easier to float in, right? Why is that? How does the salt make the ocean denser?
> **Student D:** Um, so didn't we say it was about the salt and water molecules, and how deep it goes…
> **Steve:** Oh, you were doing so good, and then you went into volume. You got into a volume argument because it's deeper. You're just telling me there's more water there. Let's go, try again. [Student D].
> **Student D:** Well, um, there are a lot of molecules that take up space, so like, the ocean has more molecules than pool water.
> **Steve:** Why would salt water, why would ocean water have more molecules in it… and the answer is actually on the yellow paper if you have it.
> **Students:** [inaudible, murmuring over paper].
> **Steve:** Why? Why does the salt water have more molecules in it?
> **Student E:** Because the salt… Because there's water molecules which would be the same density as like the pool water molecules, but there's also salt um molecules that are um… dissolved into it, so um, there's just more molecules in like… packed into the same space.
> **Steve:** Yeah, that's it.

By Lesson 4, Steve is continuing this style of sensemaking discussion with his students in relation to changing properties due to chemical reaction and the story Rumpelstiltskin:

Steve: Because it has different properties, excellent. So do you really think that … did Rumpelstiltskin do a chemical reaction to change straw into gold? Is it possible to do that kind of chemical reaction?
Students, chorusing: No.
Steve: Did two or more substances combine to make a new substance?
Students, chorusing: No.
Steve: Do you always know if two substances combine? That's actually part of what we're talking about today. So are you, [Student B], you're saying it's only one substance?
Student B: Yeah
Steve: …and so that makes it not a chemical reaction? Okay, [Student C], you were like shaking your head for something else it looked like—that it couldn't be a chemical reaction, 'cause why.
Student C: Well because like, well there wasn't like two substances combining, there wasn't anything happening to the straw, like they were just putting it through its thing and it just like turned into gold, like, that like, that doesn't happen.

In many cases these episodes take place between Steve and one or two volunteer speakers, but across class periods, he offers consistent opportunities for students to make sense of observations, discuss limitations of experimental procedures, and participate in a back and forth where they reason out correct answers together. In his conversations on density with students in Lessons 2 and 3, Steve makes frequent connections between the content written in the book and many phenomena that occur outside of class, acknowledging students' experiences outside class and helping them make sense of those experiences. Following their formal definition of buoyancy, Steve and his class apply the concept to a variety of examples such as salinity of the Dead Sea, the density of hydrogen and zeppelins in World War II, buoyancy, and how sound travels differently through helium and sulfur hexafluoride due to differences in the character of the gases. Often, he draws anecdotes from his own experiences (scuba diving and buoyancy, classical examples such as Archimedes water being displaced from a bathtub), but other times he responds effectively to students' stories or questions, interweaving their own experiences with things like inhaling helium balloons or listening to sounds in different media into the class discussion. In doing so, he values students' experience as evidence and helps them make sense of puzzling phenomena in ways that are scientifically accurate.

In cases where students have struggled with a concept, Steve integrates curricular lesson level phenomena and his own lesson level phenomena to make ideas clearer and give students opportunities for sensemaking. For example, in lesson 4, Steve has identified that students are still struggling with the idea that volume is not an intrinsic chemical property, so he shows students graduated cylinders with two different volumes of water and then attempts to burn two liquids (one flammable, one inflammable) as an illustration that the volume of a liquid does not provide information about its intrinsic chemical properties but that its flammability does. This not only follows up on a previous misconception but sets the stage for students to identify that burning is a chemical reaction, which is the lesson level phenomenon from the curriculum. However, Steve integrates these questions as a part of his students' ongoing questions about chemical change and the unit question about transformation of matter, rather than as a series of curricular steps they must complete to make it through the unit.

Steve also acknowledges the presence and needs of emerging bilingual students in his classroom, and adults in the building whose job it is to support them. At one point during lab in Lesson 2, he checks in with a Spanish speaking student, asking *"¿Cómo estás? ¿Así así?"* ("How are you? So-so?") to check in with a student, though without further context, it is difficult to know whether these specific comments contributed to an "othering" of ELLs and bilingual students or whether this was a successful attempt to include them and validate their skill in another language. However, at the beginning of Lesson 3, Steve explains the role of an ELL teacher in the building and acknowledges her importance. The students in his class are saying that they make fun of her because she has an American accent when she speaks Spanish, and he explains that he also has a bad accent when speaking Spanish, but that the teacher's job is to help make things understandable for students and that she does a good job of working with students as they develop greater English proficiency. In acknowledging the role of his colleague, he validates the fact that some students in the school speak languages other than English and need different kinds of support to be successful. In doing so, he validates other ways of communicating but also creates belonging for students who speak Spanish or who may need assistance with classes conducted in English.

There are two main examples of undermining behavior evidence in Steve's classroom. First, there are occasional instances of undermining students' position as knowledge generators. While Steve's instruction regularly integrates multiple examples from students' lives into class discussion, it is notable that his examples rely very frequently on examples used canonically in science textbooks. For example, he references Archimedes' displacement method and compares it to the way that volume is calculated in math class. Some of these examples are potentially inaccessible to students depending on their background knowledge in science. During most of these lab procedures, the expectation is that students should be following procedures in the exact same order, with some wiggle room for questions and figuring out the best way of taking measurements or making observations. Codes are often mixed for these vignettes as he offers swift negative feedback for incorrect and/or imprecise answers and acknowledges mostly answers that are verbally technically precise. Classes are also often teacher-directed and include just one or two students, with the rest of the class listening and Steve facilitating.

The other key undermining behavior in Steve's instruction is in relation to student belonging. Steve often uses controlling language in addressing students, enforcing strict discipline by making participation contingent on following his instructions to the letter. For example, in Lesson 1, he tells students that he will be grading them on safety and that he will take points off when he sees them making mistakes. In Lesson 3, he frames learning as being beneficial to students in terms of performing well on a test. When students make mistakes, or are unprepared, he offers swift negative feedback. While this feedback is often informational and can guide students towards generating correct answers or performing lab techniques more carefully, it often includes sarcasm. While he allows students to ask him questions in relation to their own experiences and to bring in their own experiences from outside of the classroom, he also occasionally reframes these attempts at sharing knowledge in terms of canonically or formally correct language. For example, in Lesson 4, a student told Steve that he had gone home and tried a demonstration with his dad that Steve had explained in a previous class, and that the experiment did not have the anticipated results. Steve asked a couple of clarifying questions and then concluded that the student "did not follow instructions" rather than trying to engage the student in sensemaking and troubleshooting. These instances of controlling language and enforcement of canonically correct understanding of science concepts served to undermine student belonging and took away from students' role as knowledge generators.

Three of Steve's classes (the first, second, and fourth) were coded as having a *medium* level of support. During all three of these classes, Steve maintained close control over the pace and flow of activities, whether individual, small group, or whole class. In facilitating discussion, Steve stitched together observations from class with examples from his own and students' lives and provided opportunities for sensemaking. He provided students opportunities to offer ideas and listen to one another's thinking. However, this teacher-directed approach and tight control over conversation was also occasionally the result of sarcastic or controlling language, which undermined belonging at the same time that it created a predictable and stable pattern of knowledge generation and leveraging of student experiences as evidence. In the third lesson, there was a greater frequency of shutting down sensemaking. While this third lesson did include diverse examples of science concepts in the real world, many examples were also ones canonically found in science textbooks with less room for authentic science interpretation and discussion focused around coming to a narrowly defined definition of density.

In spite of some parallels between Steve's and Amanda's classroom management styles, it is worth noting that there were no instances in the lessons coded of students talking back to Steve when he reprimanded them or corrected their behavior. This is potentially an artifact of the classes occurring later in the year when classroom routines are more established, but it could also have to do with the physical layout of the classroom. The tables in Steve's room were more spread out and students' communication with one another was more clearly focused on the members of their immediate table groups and not with communicating across the classroom or to adjacent tables.

Summary

Steve's teaching illustrates the benefit of having a high degree of familiarity with the content being taught and the ability to leverage wide-ranging examples and experiences to support student thinking. Throughout his classes, Steve frequently integrated discussion of curricular materials with outside examples that were generated by both himself and his students in order to further discussion and ask probing questions. On the other hand, his management style frequently relied on controlling language and he shut down sensemaking when students provided incorrect answers. I assigned Steve's four classes cultural responsiveness codes of medium, medium, medium low, and medium, respectively (see Table 10). The first two classes and the final class were similar in that Steve provided consistent opportunities for students to engage in sensemaking. While there were examples of undermining behaviors, particularly in terms of Steve abruptly halting discussion when students provided incorrect answers, or when he felt he had to correct misconceptions, they were brief, and the lessons flowed smoothly in terms of student sensemaking. On the other hand, Lesson 3 had relatively fewer instances of supporting codes and more examples of abrupt correction, controlling language, and shutting down sensemaking in the fact of incorrect answers.

Student Engagement

In addition to cataloguing teachers' behaviors over the course of a chemistry unit, the present research relates teachers' behavior to student engagement. Specifically, Research Questions 3 asks, "Do teachers' use of culturally relevant strategies map in any particular pattern over time against students' daily end of class reports of engagement?" and Research Question 4 asks, "Is there a difference in results… for groups considering intersecting gender and racial identities?" At the end of each class period throughout the study, students reported their engagement across four categories: cognitive engagement, affective engagement, behavioral engagement, and behavioral disengagement.

General Observations

An examination of teachers' CRT codes and students' self-reports of engagement shows a general if weak correlation between class codes and engagement. Figure 2 presents means and standard deviations for each of the three types of engagement examined in student end of class reports (behavioral, cognitive, and affective). While it is not appropriate to compare teachers' mean engagement levels on a class by class basis due to differences in student populations as well as in the content of the unit and its timing in the school year, it is interesting to note that Caroline's classes had relatively high affective and behavioral engagement reports and relatively low behavioral disengagement in spite of it being relatively early in the school year when teachers are often still developing classroom routines and norms. The standard deviation of the scores was also relatively smaller for Caroline and Sandra than it was for Amanda and Steve indicating less variability in the data. Use of state space grids allows further visualization of the experiences of students across teachers and a comparison to class cultural responsiveness. To this end, Figures 3-6 show a visual of State Space Grids for the students in the study for each of the forms of engagement. Each trajectory treats teacher actions, as coded for with CRT supports, as one relational component shown on the X axis, and student engagement reports on the Y axis. When combining students from all four teachers and looking at the sample as a whole, male students tended to have greater dispersion than female students, and minoritized students tended to have greater dispersion than white students. However, many of these correlations are weak, and were influenced by a number of factors that made the data potentially unreliable or difficult to interpret. There were multiple students with missing data on one or more items or classes, and there were also several instances where students reported the same level of engagement across all four forms of engagement. Specifically, some students reported high levels of all forms of engagement across multiple class periods, to include behavioral disaffection, which would generally be expected to behave somewhat inversely to the other three forms. This led me to wonder whether students were reading all of the items carefully before responding.

Individual Student Trajectories

While Figures 3-6 show the overall engagement reports of students across classes, a more granular view of individual student trajectories over the course of the unit reveals that different students had different patterns in terms of their engagement across the course of the unit. Viewing the trajectories of all students together in Figures 3-6 illustrates that higher reports of engagement tend to occur when classes have CRT codes of 3 or greater (i.e., at least medium supports), and that a fair number of students still report high levels of cognitive, affective, and behavioral engagement and low levels of behavioral disengagement even in the absence of high levels of support. Conversely, there are relatively few examples of cases where teachers' classes were coded as being medium high or high and students reported low levels of engagement. However, an examination of the trajectories for students who reported low levels of engagement despite higher codes for CRT may reveal important patterns or information for students who historically feel excluded from science classes and formal learning environments. In examining group level differences between students across all teachers, it is interesting that there are relatively few female outliers with low cognitive, behavioral, or affective scores in classes coded medium, medium high, or high for cultural responsiveness (Figures 3-6); nearly all outliers were male.

As an example of outlier reports of engagement, Deandre (Figure 7) is a Black male in Caroline's class who self-reported a low level of engagement compared to his peers in Lesson 3 and Lesson 4. The pattern for all four forms of engagement for Deandre are similar, showing a moderate level engagement on Lesson 1 (CE = 1.5, AE = 2.0, BE = 2.0), high engagement during Lesson 2 (CE = 3.0, AE = 3.0, BE = 3.0), and a shift to low engagement in lessons 3 (CE = 1.0, AE = 1.5, BE = 0.5), and 4 (CE = 0.0, AE = 1.0, BE = 0.0), with the inverse being seen (as expected) for behavioral disaffection (Lesson 1 BD = 2.0, Lesson 2 BD = 1.5, Lesson 3 BD = 2.0, Lesson 4 = 3.0). Of the four forms of engagement, Deandre's behavioral disengagement shows the least variability and remains relatively high across all four class instances. It is worth noting that an examination of all of Deandre's ECR data (including days which were not included in the four lessons selected for the study) reveals that a few days prior to the first lesson in the study he wrote a comment on his ECR form stating that “it was Realy fun today” [sic] and reported high cognitive, behavioral, and affective engagement and low behavioral disengagement. He did not record comments on his ECR forms for any of the days coded for cultural responsiveness supports in the study, but this willingness to engage early in the unit indicates that he is willing and able to engage but may need additional scaffolding to know how to engage productively or may have other factors that are impeding his self-reports of engagement. This raises important questions about what barriers to engagement there might be for a student beyond culturally responsive teaching strategies, as Caroline’s lowest class code in the study was medium and across lessons, she illustrated a wide range of strategies to support student engagement. Interestingly, this ‘medium’ lesson did mark a downward trend in Deandre’s engagement reports from the preceding class.

Most other students’ responses were more mixed and less consistent in terms of whether the different forms of engagement varied in similar ways over the course of the unit. Javier (Figure 8), a Hispanic male student in Amanda’s class, showed high affective engagement in Lesson 1 (AE = 3.0), which was rated as medium-low for cultural responsiveness, and moderate amounts in Lessons 2 and 3 (Lesson 2 AE = 1.5, Lesson 3 AE = 1.5), which were coded as medium-low and medium, respectively. However, in Lesson 4, which was coded as low for cultural responsiveness, Javier reported very low affective engagement (AE = 0.0). Interestingly, his behavioral disaffection and behavioral engagement stayed at moderate amounts throughout all four lessons, and his cognitive engagement showed an increase in Lesson 4 (CE = 3.0) despite his decrease in reports of affective engagement. The affective engagement questions touch on whether content is enjoyable and interesting, whereas the cognitive engagement items ask whether students are trying to make connections and understand the lesson, so we can infer that in Lesson 4, which was most notable for student misbehavior and in which several students were resisting instruction from Amanda, Javier was working hard to understand content but not enjoying class. While it is beyond the scope of the present research to investigate moment to moment interactions between individuals, it would be interesting to map Javier's engagement in response to moment-to-moment stimuli, similarly to the way that Hollenstein, Lamey, and colleagues (1999; 2013) have used a dynamic systems approach to catalogue not only changes to dynamics across multiple sessions but within individual conversations.

A further interesting example of individual student trajectories can be seen in Steve's class, where Allison, a Black female student, reported very little variation in engagement overall but whose cognitive, affective, and behavioral disaffection dipped significantly in Lesson 3 (BE = 0.5, CE = 0.5, AE = 0; see Figure 9) whilst remaining otherwise relatively stable throughout the other lessons. While there was not much variation in the CRT coding for Steve, with three of four classes being coded as medium, it was this third lesson which was coded for medium low; it is possible that Allison's dip in engagement reports is due to a particular negative interaction or lack of supports otherwise found in Steve's lessons. Allison's relatively stable levels of engagement across the unit also raise questions as to how past experiences and interest in science as a subject may or may not make student engagement resilient to changes in student-teacher dynamic, either on a class-to-class basis or across multiple years of instruction.

Interestingly, in examining the trajectories for students who reported low levels of engagement or high disengagement, it was often difficult to visualize their trajectories over the course of the unit due to missing data. Many students who reported high levels of disengagement or low levels of engagement were absent on one or more days over the course of the study. This calls into question the role that attendance may play in student engagement and ability to engage meaningfully in class. However, patterns due to attendance were outside the scope of the present research.

Summary

Student trajectories varied widely across the unit, with male and minoritized students tending to report greater dispersion in their self-reports of engagement, indicating greater time in transition and the possibility of more attractor states in the state space. Behavioral disaffection was particularly reported in nonwhite students even in classes where cultural responsiveness was coded in the medium, medium high, or high range. As noted previously, some irregularities in the data and difficulties in mapping a full range of teaching strategies to students across teaching conditions also made it difficult to draw firm conclusions about student engagement.

CHAPTER 5: DISCUSSION

The present research attempted to understand patterns in teacher practice while implementing NGSS and using motivational design. This dissertation study catalogued the practices of four teachers integrating NGSS with supports for student motivation. Motivationally supportive classrooms were an appropriate setting because teachers identified as being interested in supporting student motivation and as such were likely to implement strategies across the spectrum of student motivational supports. Further, NGSS-based instruction is designed to provide equitable access to science learning through guided discussion and observation of universally accessible phenomena, though several critiques have been leveraged indicating that it falls short of true cultural responsiveness. Teachers' instructional patterns in this context were in turn mapped to student self-reports of engagement. Several themes emerged across classrooms that can be leveraged to improve implementation of NGSS to provide equitable access to science learning.

Teacher Practice

Across the study, relevant teacher behaviors were coded as being alternately supporting or undermining. Identification of infrequently used codes revealed gaps in practice or missed opportunities in terms of motivational support and cultural responsiveness. The following sections detail each of these areas in turn.

Supporting behaviors

The most consistently applied strategy across all four teachers was the opportunity for students to generate knowledge. This is unsurprising given that the NGSS Lesson Screener used to vet curricular materials (Achieve, 2016) expressly identifies scripted "right" answers or explanations for phenomena as being inappropriate, suggesting that students should participate in sense-making as a part of the learning process. There is also clear alignment between what NGSS terms as sensemaking opportunities and Kolonich et al.'s (2018) Framework element positioning students as knowledge generators. When teachers facilitated NGSS-aligned curricula in light of a guiding unit phenomenon, using classroom experiences to create discussion around ideas that are generated and revised together, they create opportunities to highlight and leverage student language and voice and use students' experience as evidence as a part of the knowledge generation process. Accordingly, these latter two categories of supports were also used in multiple class sessions by multiple teachers. Specifically, regarding use of student language and attribute of ideas to students, teachers frequently mapped student thinking, ideas, and definitions over the course of the unit. For example, Amanda and Sandra used anchor charts to track student thinking, with Sandra specifically using a driving question board to keep track of ideas that students have generated and what ones they have resolved, while Caroline asked students to revise ideas after conducting additional reasoning. This is evidence of teacher experience with implementing NGSS and with teacher use of NGSS-aligned materials which often reference driving phenomena and sensemaking as well as centralizing student questions as a part of the learning process.

It is worth noting that most opportunities for knowledge generation and leveraging of student language in the unit—both in the curricular scaffolds and in teacher-facilitated conversation—relied on universally accessible examples and not culturally-situated ones. Selection of culturally neutral phenomena is a double-edged sword: on the one hand, by using universal experiences, such as ice melting or mixing salt with water, teachers provided sensemaking opportunities that were equally available to all students; on the other hand, this approach omits potentially important strategies and examples that proactively include marginalized groups. As Collins (2021) explains, culturally responsive teaching must specifically incorporate opportunities for students to solve problems that are important to their communities or at minimum tell the stories of people who look like them and share their successes. Specifically, she writes that teachers must:

> "intertwine classroom content with the stories and intellectual achievements of women and chemists of colour. Chemists can tell very compelling stories using the molecules or systems that we choose to investigate; why not tell the stories of the chemists behind the compounds too — such as that of Ball while discussing organic esters — ensuring that everyone's contributions are captured?" (Collins, 2021, p. 1)

It could be argued that exploration of other curricular units with less claim to seemingly acultural content would better lend themselves to student-generated terms and culturally situated solutions, and that chemistry as a topic is acultural by nature. These arguments overlook the fact that chemicals and chemical change are so ubiquitous, it is less a matter of being unable to connect middle school content to issues of environmental or racial justice and more a matter of additional care for teachers and curriculum designers to find relevant examples. Collins (2021) uses the example of asking where on the periodic table the fictional element vibranium (from the movie *Black Panther*) would go, but also cites issues in water quality in Flint, Michigan, additives in food, and lead exposure in inner city as issues that students can begin to ponder and understand from the lens of chemistry learning. As the NSTA asserts in its declarations in support of teaching the Nature of Science (NOS):

> "Contributions to science can be made and have been made by people the world over. As a consequence, science does not occur in a vacuum. It affects society and cultures, and it is affected by the society and culture within which it occurs." (AAAS 1993; Showalter 1974).
>
> and
>
> "The scientific questions asked, the observations made, and the conclusions in science are to some extent influenced by the existing state of scientific knowledge, the social and cultural context of the researcher, and the observer's experiences and expectations. Again,

> scientific knowledge is partially subjective and socially and culturally embedded" (Lederman & Lederman 2014; NSTA 2000).

However, the Nature of Science is placed in a matrix alongside the science practices and crosscutting concepts in NGSS in *Appendix H*, and do not address a particularly nuanced understanding of issues of social justice, particularly at the middle school level. This is consistent with previous research in science teaching. Practices identified as being part of equitable instruction for "ambitious science teaching" were shown to help novice teachers from dominant communities if they simultaneously problematized their previously held views about science teaching and learning; however, these practices did not necessarily assist teachers in developing critical consciousness about racism or systemic inequity (Kang & Zinger, 2019). Conversely, teachers who show cultural competence have been described as having vast cultural knowledge and an ability to take advantage of students' existing linguistic and content skills as an asset for learning (Calabrese Barton & Tan, 2009; Rosebery et al., 1992). Unfortunately, teachers and researchers have found areas of tension even when implementing NGSS and attempting to integrate community-based concerns such as heavy metal contamination, meaning that the standards themselves may constrain how these practices are enacted (Morales-Doyle, et al. 2019).

Another key theme in teacher practices was provision of supports for belonging. Unlike supports for sensemaking and knowledge generation, neither Kolonich and colleagues' Framework nor vetting tools for NGSS curricula focus on development of interpersonal relationships between students or between teachers and students. On the other hand, instructional design and planning to support student motivation includes belonging as a primary design principle, while culturally relevant pedagogies emphasize culturally relevant caring (Parsons, 2005) or being a warm demander (Hammond, 2018), illustrating the importance of creating an environment where students feel valued and perceive that their teachers have high expectations for them. While teachers were explicitly trained in supporting student belonging during their professional development, their NGSS-aligned curricular materials did not explicitly incorporate belonging supports. Broadly speaking, exhibitions of culturally relevant caring and provision for student belonging are less embedded in curricula and discussion scaffolds and more evident in teachers' daily, ongoing, and consistent interaction with students. Further, belonging is not just social belonging in classroom or having high expectations for students, but also holding space for students to explicitly identify what it takes to do science in the classroom. For Caroline, this was illustrated by discussions about what tools are available. For Sandra, it meant making sure that everyone's voice was heard and being explicit about having everyone have a role within a group.

Because of the consistent application of strategies to support student belonging, providing explicit instruction on the norms of school and showing students ways of participating fully as a classmate, teammate, or scientist was one code that was added to the *a priori* coding scheme. Conceptually, this behavior is similar to what Calabrese Barton and Tan (2019) describe as making explicit the goals of the educational system: in order to truly feed into belonging, students need to be given the opportunity to identify how a classroom works, how they can help one another, and what tools they have at their disposal to work effectively in a classroom environment.

Teachers leveraged these three strategies/approaches differently, perhaps partially due to differing academic and professional backgrounds. Steve and Amanda had undergraduate degrees in the sciences and teaching experience primarily in math and science. Their classrooms provided the richest evidence of seamless integration of sensemaking and incorporation of multiple examples of a single concept in sensemaking episodes. This illustrated a high degree of content knowledge (CK). Teachers with strong content knowledge are well-positioned to leverage student FOK and assist in drawing out students' experiences as a source of evidence. On the other hand, Sandra and Caroline had undergraduate degrees in areas outside the sciences and teaching backgrounds encompassing a greater range of subjects and grade levels; their classrooms provided the most varied applications of belonging support reflecting a high degree of nuanced pedagogical knowledge (PK). Over the course of the unit, as the teachers leveraged varying degrees of integration of these two forms of knowledge, they each illustrated a variety of forms of pedagogical content knowledge (PCK). Previous research has found that PK, CK, and PCK are learned independently, and that instruction in two forms do not necessarily translate to familiarity with the third (Evens et al., 2018). Further, illustration of these forms of knowledge in the present study did not necessarily correlate with an ability to integrate student or community culture into the classroom. It follows that cultural knowledge—or perhaps cultural pedagogical knowledge—is a separate entity from these other forms of knowledge traditionally addressed in teacher education and that culture should be explicitly addressed in teacher professional learning.

Undermining behaviors

Across the study, there were several ways that teachers illustrated undermining behaviors, although it is important to note that some of these behaviors may have been the result of forces and requirements outside of the classroom locus of control. First, while curricular materials often aided teachers in scaffolding effective discussion, use of packets and the need for students to follow a predetermined sequence of events occasionally undermined authenticity in conversation. Steve notably did a good job of using the workbook as a place to record student thinking as he wove discussion throughout the storyline and integrated his own examples; in other cases the purpose of the class seemed to be filling out the workbook.

A further theme in undermining behavior had to do with power dynamics in the classroom and the occasional use of controlling language, sarcasm, or negativity to redirect misbehaviors. In a handful of cases, students engaged in namecalling, drawing on desks, or destroying lab materials, illustrating the very real need for teachers to execute instructional moves and protect instructional resources while maintaining a safe learning environment for students. Teachers occasionally used controlling language such as "I need you to", "my classroom", or "my materials" rather than "we" or "our" language and enforced rules as a compliance strategy when students illustrated signs of misbehavior or inattention.

The invocation of rules for compliance and enforcement of specific behaviors in a science classroom can be seen from two perspectives: first, it could be argued that being able to behave within specific guidelines is a safety issue. It could also be argued that protectiveness about the lab space and student materials results in learning tools that are available to all students, including students who will take the class in subsequent years or even just the next class period. As described in Calabrese Barton and Tan (2020), however, this protection of the space "for all" often neglects the need for classrooms to explicitly disrupt learning hierarchies and create space particularly for students of color to explore their own academic identities and to take ownership over the learning process. As an example, in the present study, emerging bilingual students' thoughts and ideas and their cultural FOK were often omitted in discussion because learning was framed as completion of a scripted set of tasks, adding written competence in English as a criterion for being able to capture scientific thinking rather than leveraging student knowledge. It is possible that an approach more reliant on norms generated in part by students may allow students to take more ownership over rules and procedures and framing those norms as part of a culture of care, teachers can address potential challenges to participation while maintaining a high expectation for safety and behavior.

While it was beyond the scope of the present research to examine fully, it is also worth noting that the physical environment available to teachers greatly impacted teachers' ability to interact effectively with students and their ability to leverage a variety of strategies. As a primary example, Amanda's lab tables were organized in a multilevel stadium style seating and labs had to be done in trays to avoid getting on the carpeted floor. Her class of 32 had difficulty clustering around tables during lab and by default she had to spend a lot of time at the center of attention at the bottom of the room. Conversely, in Steve's room, there was ample room for tables to be spread out and for students to interact more comfortably and for Steve to move between tables.

Missed opportunities

Two key areas of support were consistently not observed in the study: leveraging students' FOK and promoting students' critical lens to solve problems. While students' experiences were frequently invited and referenced in class discussion as evidence for science phenomena, most of these examples were not culturally situated and did not highlight, validate, or explore varying viewpoints with the goal of leveraging FOK or helping students understand marginalizing school and life experiences. A funds of knowledge perspective allows teachers to not only incorporate student thinking into the classroom but to actively draw on cultural and community knowledge that exists outside the classroom and to intentionally relate learning to community history (Moll et al., 1992; Gonzalez et al., 2005). The unit phenomenon in the district-created curriculum used by Amanda and Caroline did relate to an issue that was potentially relevant to their community in that students were challenged to address a need for desert tortoises. However, it is unclear whether this phenomenon was personally important to students. The classes occurring in the middle of the unit only occasionally referenced what chemical reaction the students would use to keep the turtle eggs warm or relate developing knowledge back to turtle eggs as a community problem. True integration of a unit phenomenon allows students to progressively build understanding of a driving question or phenomenon; the unit could just as easily have included a student-selected unit phenomenon.

Notably, these two areas of support most frequently omitted potentially require the deepest understanding of students' cultural realities and the greatest personal commitment to using the classroom as a place to address issues of social justice, and as Calabrese Barton and Tan (2019, 2020) have noted, culturally neutral language and insistence on leaving issues that could be construed as political as belonging outside the classroom actively undermines students' ability to develop a critical lens. It is notable that none of the teachers in the study actively undermined students' ability to use a critical lens, but nor did they actively provide opportunities to develop it. While the primary supports noted in the study—positioning students as knowledge generators, using their experiences as evidence, validating their linguistic contributions, and supporting their belonging—go part way towards centering students' experiences and validating their cultural realities, they are insufficient to address issues of social justice and inequity, and therefore fall short of cultural responsiveness.

Given the preceding examples, the present research illustrates that culturally responsive practice was most evident through framework elements that are codified in the standards themselves and in the structures that are detailed in Windschitl and colleagues' (2012; 2018) view of ambitious science teaching for equity and phenomenon-based learning. Teachers provided additional supports potentially rooted in their pedagogical, content, or pedagogical content knowledge, but were less likely to execute practices which involved application or expression of cultural knowledge or recognition of the culturally situated Nature of Science (NOS). These more justice-oriented practices are less explicitly described in the NGSS themselves, although they are central to the work of researchers such as Kumar et al. (2018) in their description of achievement motivation and culturally responsive and relevant education. However, it would seem that the culturally-situated nature of science learning and the need for teachers and learning institutions to legitimize and value multiple backgrounds and heritages and center the experiences of nondominant students and communities has not yet made its way into the mainstream of teacher preparation and practice.

As an example, in my review of the literature, I identified synergy between Kumar and colleagues' description of competence, Kolonich and colleagues' (2011) Framework elements 1 (knowledge generation) and 3 (student language) and Linnenbrink-Garcia and colleagues' (2016) motivational design principle 1 (support for student competence). However, it is noteworthy that only Kumar and colleagues' work explicitly referenced the notion that students should develop competence through tasks that energize and empower them to question sociopolitical inequities; the other two framework elements emphasize competence more generally. Similarly, Kumar and colleagues' discussion of agency and autonomy aligns with Design principle 2 (autonomy) (Linnenbrink-Garcia et al., 2016), but only Kumar et al.'s work explicitly references socio-political consciousness and the need to question cultural hegemony. It can be concluded that, while teachers may have supported equitable instruction and student motivation through a more culturally-neutral lens of equity and inclusion, their existing practice did not fully reflect the full breadth of what it means to be culturally responsive in terms of active empowerment of historically marginalized or oppressed student groups. As noted in the literature review, this approach to equity and student motivation is certainly critical, but omission of macro-level cultural context and the importance of developing cultural competence causes potential problems especially for minoritized student groups. Given this, it is important to consider not only teacher practice but potential impacts to students' experiences of the classroom.

Given the emphasis in the *Framework* on equity, its lack of integration in the standards, and the fact that culturally responsive teaching requires deep understanding of students' cultural and sociopolitical realities, teachers must be given additional time and support in order to become more fully culturally responsive. This time is essential to developing deeper knowledge of students' communities and to forging partnerships with community members who can help teachers identify the problems and phenomena that students will most need to understand as adults. As exemplified in the Glynn (2020) study of Māori elders and science teachers working side by side to help students learn about western and traditional viewpoints, teachers can serve both the role of leader and the role of learner when it comes to understanding their students' communities and deep culture. Ultimately, this kind of partnership will empower teachers to better understand the ways that science learning can support and sustain students' communities and help make the science classroom a place to understand the culturally situated nature of science (NSTA, 2000).

Student Engagement

Conclusions drawn from student engagement measures were limited, but revealed a number of key patterns. Student engagement reports tended to be highest with at least medium levels of cultural responsiveness; however, there was a great deal of variation in patterns in individual student trajectories. For some students, patterns across forms of motivation were similar; for others, during class periods with particularly low levels of motivational support, one form of motivation increased and another decreased; for still others, motivation was relatively stable across the unit despite differing levels of classroom support. It was unfortunate but also perhaps telling that comparison between white and nonwhite students was difficult in some cases because the range of CRT codes was lesser for classrooms with only large numbers of white students. Namely, classes with predominantly white students did not have any classes coded as ‘low’. Conversely, there were several instances where students reported high levels of one or more forms engagement despite low CRT coding, indicating that student engagement is potentially influenced by, but not entirely dependent on, teacher CRT supports. Additionally, deep visualization and discussion of differences based on intersecting identities was not possible from the given data: for one, there were significant differences in socioeconomic status between student groups, so the experiences of students of one minoritized student in one classroom was not necessarily comparable to the experiences of that same group in another, and the lack of variation between classes for most teachers in terms of their CRT ratings made it difficult to visualize the full breadth of the interplay between teacher practice and student engagement.

A variety of other factors may have also played a role in student engagement. Notably, the time of year that teachers implemented their chemistry unit varied by district, and accordingly, their relationships with students were more or less settled, which potentially impacted their management of misbehaviors. As an example, Amanda and Steve showed similar use of controlling language but students seemed more inclined to push back against Amanda; this may have been an artifact of the unit being observed at the very beginning of the year when norms were less settled. Options for student seating also likely impacted management and interaction between students and between students and teachers. Amanda’s stadium-style classroom and Caroline’s crowded tables impeded their movement around the room at least to some extent, while Steve was able to move easily from one place to another. Further, all four teachers experienced interruptions or disruptions to the flow of conversation and meaning making in the form of phone calls, students coming in late, or the need to address absent students. Because the study captured all four teachers in various modes of instruction (discussion, lab, response to a written prompt, etc.), CRT codes may also have changed as a function of the type of instruction. Many of these variations were not effectively captured in the data. Further, the engagement items did not capture all potential forms of engagement. Specifically, it did not include measures of agentic engagement, which has previously been identified as a pathway to achievement that involves students proactively influencing the learning environment through behaviors that alter the flow of teaching and enrich the learning environment (Reeve, 2013), or a social dimension to engagement (identified/validated by Wang, et al., 2016). Wang and colleagues (2016) also noted the imperative to consider disciplinary engagement across a range of diverse ethnic and socioeconomic groups and alongside information on engagement from multiple informants to provide a more valid indicator of engagement across multiple dimensions; in the present study, such rich description was not possible, although this would be an interesting topic for future research.

Implications

The present research has potential implications for teacher professional learning and curriculum design and contributes additional descriptive examples to existing theory on culturally responsive teaching. Teachers' professional learning at the outset of the study familiarized them with principles of motivational design, and many of these principles were apparent in their teaching over the course of the study. However, as noted in the literature review, motivational research and motivational design often generically address the needs of individuals without deliberate attention to marginalizing experiences of female students and students of color (Kumar et al., 2018; Usher, 2018).

All four teachers in the study illustrated competence in some of the tenets of what Windschitl and colleagues (2012, 2018) have termed "ambitious science teaching": use of planning and elicitation of student ideas to support changes in students' thinking around key phenomena and creating evidence-based explanations. However, none of the four teachers illustrated consistent application of the full breadth of strategies that entail true cultural responsiveness. Rather, the study illustrated a potential dichotomy in the way that teachers supported students. For example, Caroline and Sandra both applied a variety of strategies that supported belonging and interpersonal relationships in the classroom, showing deeper experience with a variety of pedagogical strategies and well-developed pedagogical knowledge. These behaviors illustrated the importance of teacher behavior in promoting belonging not only in an interpersonal sense but also in making explicit the kinds of cognitive and material resources that students must draw on in different kinds of instructional episodes, and during qualitative coding, an additional belonging support category was added to the *a priori* coding scheme to include Christine's practice of making classroom structures and routines explicit. Conversely, Steve and Amanda consistently leveraged rich examples of curricular content across a variety of examples from outside the classroom, showing strong content knowledge. Drawing a distinction between what constitutes teacher pedagogical, content, pedagogical content, and cultural knowledge may assist in making appropriate shifts for teachers in their professional learning. Namely, teachers who actively seek to grow in their own learning about their students' cultures may be more likely to create inclusive learning environments, particularly in instances when there is a cultural mismatch between teachers and their students.

Omissions and gaps in strategy use revealed a relative lack of application of pedagogical content knowledge or cultural knowledge to a unit that is traditionally presented in a narrow, “color blind” way. Conversely, Kumar et al.’s (2018) framework for culturally responsive and relevant education underscored the interrelations between cultural and academic competence, indicating that development of cultural competence was important for both teachers and students in order to support student learning. This also raises questions about the cultural match or mismatch of students in the study: lack of cultural competence has previously been attributed to differences between teacher and student cultural background (Hollins & Torres-Guzman, 2005), so it is possible that, particularly for white teachers in culturally diverse classrooms, additional professional learning and reflection may be needed to develop cultural competence and assist students in developing it as well.

Training in cultural responsiveness can further support teachers teach discourse that validates all perspectives and allows students to draw on past experiences while still guiding students in sensemaking and understanding phenomena and standards outlined in NGSS. It is of course difficult to incorporate cultural learning in teacher professional development because of the localized nature of culture, but perhaps part of teachers’ training should be to have time to look at phenomena that could be better understood as case studies in their local communities, or to challenge teachers to take time to plan for lessons that can be adjusted based on phenomena that students generate rather than relying on universal examples.

Design of future curricula for implementation with the NGSS can potentially provide additional instructional scaffolds that invite culturally situated conversation and better leverage student FOK. Teachers in the study used a variety of resources that encouraged them to elicit student ideas and encourage students to track their ideas over the course of the unit; perhaps these kinds of materials can be modified to incorporate guiding questions that validate and include alternate perspectives and community-based knowledge without over-reliance on culturally neutral examples. As noted in the literature review, the National Science Teachers Association acknowledges that science knowledge is culturally situated and that “contributions to science can be made and have been made by people the world over.” (NSTA Board of Directors, 2020). Further incorporating this key facet of the Nature of Science in curricular materials opens a door for teachers in turn to discuss how science is understood and represented in a variety of contexts as a routine part of classroom practice.

During the process of writing memos and qualitative coding, several questions also arose that could be fuel for further research or consideration into how best to implement culturally responsive teaching practices in science classrooms. Specifically, there were several circumstances where codes were unclear, or could be coded as either supportive or undermining depending on how lens of the observer. For example, warm demander pedagogy (Ware, 2006) emphasizes the idea of communicating high expectations to students in a way that is characterized as a “demand”, and the motivational design principles indicate that informational feedback may be used as a way of providing students’ information about their progress as learners and supporting student motivation. The teachers in the study alternately showed warmth (particularly Sandra and Caroline) and a demand for precision and rigor in discussion (particularly Steve), but there were also cases which were coded as undermining behaviors due to use of sarcasm or controlling language. This raises questions about how high expectations are communicated to students, and how teachers can take on a demanding attitude without being negative or controlling.

Limitations

Culturally responsive teaching is multidimensional, encompassing a variety of facets including learning environment, relationships, instructional techniques, management, and assessments (Gay, 2018). However, the present research is delimited by its focus on student engagement and the strategies and moves that teachers take during class sessions, with an intention to broaden what is known of culturally responsive practices in the science classroom and student motivation. It does not consider curriculum, discipline, physical space, or social systems in the classroom, or the role that teacher beliefs played in influencing student engagement. Curricular materials were used to provide context for instructional decisions, but a full analysis of the cultural relevance of curricular materials is beyond the scope of the present research.

The teaching environment of the study was somewhat unique, rendering it difficult to generalize to other classrooms. The teachers in the study self-identified as being interested in supporting student motivation and received training on teaching using motivational design. However, any conclusions may be generalizable to other teachers receiving similar education who have the requisite awareness and desire to learn to support students' motivation. Further, the teachers and schools in the study were a small sample and not representative of the diverse demographic configurations of American students. Specifically, the study included only one Black teacher and one male teacher, and while different class sections have varying proportions of racially and ethnically diverse students, the classes studied do not capture the breadth of teaching and learning environments in the United States or the possible demographic configurations in the classroom.

While some of the analyses of student engagement reports focused at the level of individual student experiences, most focused on grouping students by demographics. There are critical limitations to grouping students in terms of white nonwhite categories, as it assumes that the classroom experiences of one marginalized community mirrors that of another. The study included students who were Black, white, Latinx, and Native American, and further research might continue to paint a more granular picture of their experiences, but this was outside the scope of the present research. Individual student trajectories revealed different kinds of patterns that may be indicative of a variety of student motivational profiles. Past research (e.g. Gillet et al., 2017) has shown that students with different motivational profiles regulate behavior and attention differently in formal learning environments, and that some of these profile memberships differ by gender (Opperman et al., 2021). It would be interesting to combine analysis of students' motivational profiles with their self-reports of engagement and whether these profiles indicate any patterns in their attractor states.

Further research might also apply state space grids more frequently over the course of a unit, or over a greater length of time with more observations to better understand patterns in student engagement. Similarly, more frequent measurements or observations (perhaps more using an ESM approach), or observations that take into consideration the length of time in each attractor state, might lend additional understanding to students' engagement in class. Alternatively, triangulating individual state space grids with more qualitative descriptions of students' experiences based on student interviews or other qualitative methods might assist in increasing the validity of quantitative data Further research into cultural responsiveness in the science classroom might include application of the same coding scheme to teachers who are actively enacting justice-oriented practices into their classes, or a moment-to-moment approach to behavior using SSG analyses. Specifically, time-based observations of teacher behavior (such as those studied by Pennings, et al., 2014a, 2014b) may lend a more granular understanding of the micro-level fluctuations of teacher behavior, variability within attractor states, and corresponding behavioral profiles. Employing qualitative methods not only to teacher practice but to student interviews or student discussion might also help reveal how students experience engagement in a variety of forms in the classroom.

Conclusion

All four teachers in the study showed some degree of execution of Windschitl's (2012) "ambitious science teaching" practices in their classrooms. Specifically, they used unit or lesson level phenomena, intentional support for student discourse, and revision of student ideas over the course of the unit. All four teachers also showed strategies that support motivation, notably through supports for student belonging, which is not as explicitly included in NGSS. These supports reflected both pedagogical and content knowledge relating to belonging as well as strategies to support student knowledge generation, sharing of student language, and consensus and revision of ideas through classroom facilitation and sensemaking. Broadly speaking, many of the behaviors implemented in their classrooms could be seen as being culturally responsive.

However, as others (e.g. Kang & Zinger, 2019; Lowell & McNeill, 2022) have described, this kind of general shift in professional learning towards student-centered pedagogies may not be enough to change teachers' beliefs and behaviors. As Kang and Zinger (2019) found, teachers must also develop critical consciousness and challenge their own deficit views about students in order to become fully culturally responsive. While NGSS encourages problem-solving in the context of narrowly defined curricular materials and effective classroom discourse practices can enable teachers to build from one another's ideas to solve problems, full and effective implementation of NGSS is insufficient to promote students' critical lens to solve problems in their communities, critique discourses of power, promote equity, and leverage the full range of student funds of knowledge. In the study, teachers generally started units out with students generating ideas around a central topic and high use of student language and questioning, did their best to continue to use student examples and definitions, and made attempts to come back around to central theme, but in many cases the examples that were used to stitch together student understanding were not from students' own lives or experiences but rather from "classic" demonstrations such as the burning of magnesium. Students were able to engage in sensemaking and received support from their teachers in doing so, but this sensemaking was not generally done in relation to culturally situated problems or phenomena. These findings therefore provide further evidence of critiques leveraged by a variety of practitioners and researchers (e.g. Rodriguez, 2015; Morales-Doyle, et al., 2019) that as written, even with pedagogical supports from experienced teachers trained in motivational design, is not sufficient to create a learning environment that is culturally responsive.

The study also illustrated the varying roles of pedagogical knowledge, content knowledge, pedagogical content knowledge, and cultural knowledge in supporting student motivation. Sandra and Caroline both showed regular integration of pedagogical moves outside the curriculum that helped facilitate community building and helped students identify as scholars and scientists. Steve and Amanda both drew fairly seamlessly from a bank of content knowledge spanning a variety of tools and resources, easily interweaving curricular examples and student answers, indicating a high degree of content knowledge. To some degree, all teachers illustrated pedagogical content knowledge as they discussed content in developmentally appropriate ways. Further research may investigate the intersections of these forms of knowledge with teacher cultural knowledge. Additional research may also investigate the extent to which teachers are encouraged/trained to consider examples from outside the curriculum versus being asked to stick to canonical examples or predetermined responses. Future research should also consider how the planning process could facilitate incorporation of student funds of knowledge in order to better incorporate a variety of culturally situated ways of knowing into more culture-neutral examples written into curricula.

The present research places NGSS –based instruction using motivational design as a stepping stone towards cultural responsiveness science instruction. It also identified several areas where teachers, researchers, curriculum designers, and professional developers can continue to refine current best practice to include a greater breadth of cultural realities in science teaching. Specifically, future work should emphasize culturally-based facets of the nature of science, community funds of knowledge, greater opportunity for students to apply a critical lens to community problems to enact change through a lens of social justice, and greater curricular flexibility to include examples and stories relevant to students' home communities. Finally, teachers need additional opportunities and support in order to form the kinds of relationships with students and their communities that allow them to leverage and respond to community-based funds of knowledge.

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APPENDIX A: TABLES

Table 1. *Alignment among motivational design principles, achievement motivation and culturally responsive and relevant education, and related literature on equity pedagogies relevant to science classrooms*

Achievement Motivation and Culturally Responsive and Relevant Education[2]	**Motivational Design Principle**[1]	**Equity Pedagogies in Science Teaching**
Competence: • Academic competence is predicated on cultural competence. • Culturally relevant practices related to academic competence and greater success in school. • Teachers with high cultural competence assist students in interweaving cultural and academic identities to promote both cultural and academic competence for students. • Students are energized through challenging tasks that give them the opportunity to co-construct knowledge and question sociopolitical inequities.	*Design principle 1:* Support competence through well-designed instruction, challenging work, and informational and encouraging feedback	• *Framework element 1:* Students are positioned as knowledge generators alongside teachers; teachers adopt an asset view of student contributions.[3] • Teachers build classroom connection through talk so that the entire classroom can grow intellectually. Teachers provide feedback on ideas and on classroom structures for participation.[4] • *Framework element 3:* Encourages the use and sharing of student language to affirm students' contributions without imposing stereotyped expectations onto students. Teachers adopt and support development of common language to help students make sense of phenomena.
Autonomy: • Personal and collective agency give rise to intrinsic motivation, a sense of power, and feelings of agency. • Students are allowed to manipulate materials and ideas and empowered to become socio-politically conscious and question cultural hegemony; cultural basis for interests and values is acknowledged. • Autonomy is seen as both a product and a process: students achieve empowerment by attaining autonomy, and also exercise and assert agency and autonomy when they encounter racism or discrimination.	*Design principle 2*: Support students' autonomy through opportunities for student decision making and direction.	• *Framework element 5:* Promotes the use of students' critical lens to solve problems. Students engage in critique and argumentation, evaluating one another's ideas, critiquing and evaluating work not only in the classroom but in the community. • Teachers recognize and give voice to all students' contributions, stitching together student ideas in to produce meaningful scientific ideas.[4]
Meaningfulness: • Teachers acknowledge legitimacy of multiple backgrounds and cultural heritages. • Use of content that is culturally and personally relevant. • Regard is given to interest, importance, or usefulness for the learning experience.	*Design principle 3:* Select personally relevant, interesting activities that provide opportunities for identification and active involvement.	• *Framework element 2:* Elicits, values, and leverages FOK (funds of knowledge), actively dismantling deficit perspectives and affirming students' experiences and cultural knowledge.[3]

Table 1 (cont'd)

• Strategies are aligned with students' values, attitudes, behavioral expectations, • Learning is defined as culturally situated, validated, collaborative, and dialogic, and legitimizes students' cultures.		• *Framework element 4:* Values students' lived experiences as evidence. Students bring in examples from their communities as evidence and teachers value students' lived experiences outside of class as scientific evidence.[3, 4] • Students openly and safely critique official knowledge and see content through multiple paradigms.[5]
Relatedness: • Teachers care genuinely about students, relationships are characterized by care, and students have strong relationships and connections to the school community.	*Design principle 5:* Support feelings of relatedness and belonging among students with teachers.	• Students and teachers jointly construct ideas and make meaning together as a way of building community and coming to shared understanding.[4] • Students make connections between their home cultures and academic culture.[5]
Culture: • Culturally responsive and relevant education takes a critical position on institutionalized inequity, racism, and imbalances of power, and teachers consider their role in that inequity. • Students' motivation is not only a function of microlevel classroom environment (instructional context, school climate, and interpersonal relationships) but also macrolevel cultural, historical, and sociopolitical factors. • Learning is culturally situated.	*Design principle 4:* Emphasize learning and understanding and de-emphasize performance, competition, and social comparison (culture is also indirectly discussed in MDP 3 through student values, but issues tied to race and oppression are not always expressly identified in motivation literature).	• Rigor is defined as making progress on ideas and learning goals through mediated action of teachers and discursive interactions rather than predetermined qualities in instructional activities.[4] • Students value their own and others' perspectives. Learning is defined as what students know and are able to do as a result of interactions with teachers, not performance on tests.[5] *Framework element 5:* • Use of critical lens to solve problems. Students focus on analyzing questions, examining scientific arguments, and critiquing ideas with the intention of developing a critical lens.[3]

[1]Linnenbrink-Garcia, Patall, and Pekrun (2016)
[2]Kumar, Zusho, and Bondie (2018)
[3]Kolonich, Richmond, and Krajcik (2011)
[4]Thompson, et al. (2016)
[5]Aronson & Laughter (2016)

Table 2. *Research participants*

	District A		District B	
Teacher	Caroline	Amanda	Sandra	Steve
Sex	Female	Female	Female	Male
Race/ethnicity	White	White	Black	White
Education	BA: Education MA: Education, Reading, & Literacy	BA: Geology; MA: Secondary Education	BA: Business MA: Elementary Education	BA: Chemical Engineering; MA: Education
Teaching experience	23 years	13 years	15 years	23 years
Curriculum	District-created	District-created	IQWST**	IQWST**
# of students in class	36	25	20	21
Class racial composition (% non-white)	33	100	95	33
School English Language Learner (ELL)*	2.5	26	N/A	32
% free/reduced lunch*	35	78	39	50

*Estimates based on school/district data

**Krajcik, Reiser, Sutherland, & Fortus, 2011

Table 3. *Student Self-Reported Engagement Items*

Behavioral Engagement[1]
Thinking about class today:
- How hard were you working?
- Were you paying attention?

Behavioral Disaffection[1]
Thinking about class today:
- Was your mind wandering?
- Were you just acting like you were working?

Cognitive Engagement[2]
Thinking about class today:
- Did you try to connect what you were learning to things you have learned before?
- Did you try to understand the lesson?

Affective Engagement[3]
Thinking about what you did in class today?
- Was it interesting?
- Did you enjoy it?

[1]Skinner et al., 2009
[2]Fredericks et al., 2016
[3]Linnenbrink-Garcia et al., 2010

Table 4. *Coding Scheme for Qualitative Analysis*

Framework element	Examples	Undermining examples	Likely instructional context
Positions students as knowledge generators	• Students generate and evaluate ideas[1] • Students develop explanations by analyzing data[1] • Teacher validates students' contributions, attributing ideas to students, using student ideas[1] • High expectations communicated for all students[1, 2, 3] • Explicitly placing students in control of the direction and pace of learning[3] • Asking students to engage in sensemaking[6]	• Teacher uses only definition or examples from curricular materials • All students must come to a predetermined conclusion or follow a predetermined instructional sequence • Explanations are not written in students' words • Low expectations communicated to specific students or groups	• Introduction to class (time to generate ideas) • Whole class and small group discussion (validation of student contributions, communication of expectations) • Design of lab or activity (students in control of direction) • Sensemaking episodes; analysis of findings and discussion of data (opportunities for students to communicate key findings)
Elicits, values, and leverages funds-of-knowledge (FOK)	• Provide opportunities to share cultural or community FOK[1] • Encourage students to share FOK[1] • Leverage FOK to promote science learning[1], connecting personal cultural references to academic skills and concepts[5]	• Exhibitions of cultural or community FOK are ignored, reframed, or "corrected" to reflect formal scientific understandings • Lack of opportunity to demonstrate FOK • Failure to connect to students' FOK • Failure or refusal to address historical injustices impacting membership in scientific fields[9]	• Introduction to class (acknowledgment of students' prior learning and experiences) • Whole class and small group discussion (leveraging examples from students, encouraging them to include their FOK in sensemaking)
Encourages use and sharing of student language	• Eliciting student language and ideas[1, 4, 6] • Using student language to connect science words and phenomena[1, 4, 6] • Use of examples from students' home cultures in discussion[4, 6] • Leverages full range of student linguistic and semiotic understanding[13] • Providing students opportunities for sense-making in relation to who they are, their culture, and what they care about[12]	• Insistence on use of formal academic language to the exclusion of students' words and descriptions • Intentional or accidental shutting down of sense-making or questioning; limiting opportunities for discussion or exploration of ideas[12]	• Throughout class in all verbal interactions

Table 4 (cont'd)

Values students' lived experiences as evidence	• Draw on students' culture and communities to enrich curriculum[1] • Value and incorporate real-world/community experiences, issues and challenges into the classroom[1, 3] • Relating student understanding to a driving question or phenomenon that all students have access to[6]	• Use of examples that center whiteness or the dominant culture (names, examples, reference points) • Use only of examples from the text without modification or examples from outside of class	• Whole class or small group discussions focusing on a phenomenon or use of evidence to explain ideas • Debate, storytelling, or anecdote
Promotes use of students' critical lens to solve problems	• Opportunity to develop critical lens through evaluation and critique of student ideas[1] • Seek and validate alternative perspectives and viewpoints[8] • Opportunity to use critical lens to explore and solve problems in classroom and community[1] • Critiquing and actively undermining discourses of power, including cultural, historical, or sociopolitical factors; shared commitment to identifying, disrupting, and reshaping epistemological and social hierarchies[5,9] • Use of science class as an opportunity to identify, understand, and address marginalizing school and life experiences in order to develop the academic skills that students will need to affect change[10, 11]	• Use of culturally neutral language or explanations • Insistence on a single correct way of completing a task or understanding a concept • Replicating "guest/host" social hierarchies[9] • Identifying historical injustices without actively disrupting present hierarchies[9]	• Whole class or small group discussion (protocols for discussing and evaluating ideas) • Design of lab or activity (instructions for how to share and combine ideas)
Belonging/Culturally relevant caring	• Exhibitions of culturally responsive caring, including acknowledgment of a wide range of hopes, dreams, and aspirations[4, 7] • Students are taught to know and praise their own and one another's cultural	• Using stereotypes or stereotyped examples; emphasizing inclusion over justice[9] • Assertion of teacher authority or power or academic hierarchy • Invocation of rules for compliance	• Opening of class session (greeting, routines) or activity (reminder of norms, roles) • In the event of a conflict or challenge (rules versus norms, structures for solving problems)

Table 4 (cont'd)

	heritages and respect difference[4] • Welcomes or calls on students by name[8] • Uses activities to promote teambuilding and collaboration[8] • Models positive self-talk[8] • Framing learning as progress towards shared/community goals[6] • Politically oriented acts of asserting student rights[9] • Addresses implicit and explicit values and goals of the educational system[9] • *Explicitly addresses behaviors and strategies that will make students successful in meeting school and classroom goals*[14]	• Lack of care for students' heritage, goals, or aspirations • Lack of scaffolding for effective communication and trust building • Making student membership in the classroom community contingent on adherence to dominant disciplinary, social, and instructional practices[9] • Placing the burden/cost of participation on the student[9]	• Discussions about performance or achievement (expectations for students, goal setting)

[1]Kolonich, Richmond, & Krajcik (2018)
[2]Hammond
[3] Gay 2010
[4] Gay 2018
[5] Aronson & Laughter, 2016
[6] Windschitl, Thompson, Braaten, Stroupe, 2012
[7] Parsons, 2005
[8] Montgomery Public Schools
[9]Calabrese Barton & Tan, 2020
[10]Calabrese Barton & Tan, 2019
[11]Morales Doyle, 2015
[12]Schwarz, Braaten, Haverly, & de los Santos, 2020
[13]Suárez, 2019
[14]Additional code added to preliminary coding scheme based on classroom observations (not captured in preliminary code list)

Table 5. *Video Instances Used for Teachers in the Study*

Teacher	Video 1	Video 2	Video 3	Video 4
Caroline	**Topic:** Chemical vocabulary: using video and reading to support a prior card sort to define atoms and elements **CRT code:** High	**Topic:** Physical and chemical changes: how to identify signs of chemical change **CRT code:** Medium high	**Topic:** CER: Has chemical change occurred? Making a claim about lab data and whether a chemical change occurred. **CRT code:** Medium	**Topic:** Preparation for culminating project on chemical change to support a project; discussion of magnet school visit **CRT code:** Medium-high
Amanda	**Topic:** Chemical vocabulary: defining atoms, molecules, and elements **CRT code:** Medium low	**Topic:** Chemical change: how to identify signs of chemical change **CRT code:** Medium low	**Topic:** Chemical change lab: searching for evidence of chemical change **CRT code:** Medium	**Topic:** Making observations of substance properties to identify substances **CRT code:** Low
Sandra	**Topic:** Definitions: matter/"stuff", physical versus chemical properties, chemical change **CRT code:** High	**Topic:** Solubility, mixtures, lab on solubility of fat and soap in oil in water **CRT code:** Medium	**Topic:** Evidence for a chemical change, using various chemical properties to compare materials **CRT code:** Medium low	**Topic:** Calculating density, additional examples of chemical vs. physical change **CRT code:** Medium
Steve	**Topic:** Observations of changing substances: copper chloride and aluminum foil **CRT code:** Medium	**Topic:** Defining properties-comparing & calculating density of objects. **CRT code:** Medium	**Topic:** Applications of density and conceptual clarification **CRT code:** Medium low	**Topic:** Burning as a chemical reaction **CRT code:** Medium

Table 6. *Summary of key findings from qualitative coding*

Framework elements	Supporting	Undermining	Omissions?
Positions students as knowledge generators (high frequency supports across teachers)	• Acknowledging student contributions to class discussion (Caroline) • Using classroom structures (grouping, routines) that encourage students to generate ideas and participate in sensemaking (Caroline, Amanda) • Facilitating conversation that gives students the opportunity to participate in sensemaking (Sandra, Steve) • Giving students procedures and opportunity to make mistakes within those procedures (Sandra, Steve) • Giving students autonomy over the way to carry out a procedure (Amanda)	• Predetermined conclusions and procedures (Amanda, Steve) • Occasional instances of shutting down sensemaking (Caroline) OR sensemaking is done only by one student and in a narrowly defined context (Steve) • Low expectations communicated to some groups of students—notably ELLs (Amanda)	• How teachers communicated "high expectations" to all students was inconsistent
Elicits, values, and leverages funds-of-knowledge (low frequency across teachers)	• Allowing students to provide examples from outside of school to make sense of science content (Caroline, Steve) • Periodic references to accessible examples such as students' backyards, Legos, (all)	• Skipping past sensemaking opportunities in the context of content that confuses students (Caroline) • Correction of student reasoning to reflect formal academic concepts or understanding (Steve)	• Nearly all examples of FOK were acultural/culture neutral and not situated in community needs/realities
Encourages use and sharing of student language (medium frequency across teachers)	• Using agreed upon terms and definitions; generating consensus about meaning (Caroline, Amanda) • Attributing specific ideas to students, repeating students' words or descriptions to validate their ideas (Caroline, Amanda, Sandra, Steve) • Using whole class discussion or grouping strategies to get students to listen to and comment on one another's ideas (Caroline, Amanda, Steve) • Acknowledging needs of students with varying needs of language support (Steve)	• Framing learning as the ability to successfully write answers in English (Amanda)	• Failure to include needs, expertise, and experiences of English Language Learners • Sensemaking is done in relation to culture-neutral concepts rather than students' culture and what they care about

Table 6 (cont'd)

Values students' lived experiences as evidence (medium- high frequency across teachers)	• Routine reference to an accessible driving question or phenomenon at the unit and lesson level (all) • Ability to make connections to a variety of phenomena and experiences (Caroline, Amanda, Steve) • Encouraging students to bring in outside examples; use of examples that all students are familiar with (all) • Reference to a real-world challenge that can be solved by students over the course of the unit (keeping turtle eggs warm) (Caroline, Amanda)	• Limited modification of curricular resources to match students' cultural identities (all)	• No opportunities for students to identify real-world problems that could be solved through their learning
Promotes use of students' critical lens to solve problems (low frequency across teachers, especially in relation to culturally-situated phenomena)	• Use of a phenomenon that could be locally relevant (Caroline, Amanda) • Creating an environment where students can comment on or critique one another's ideas (Caroline, Sandra) • Awareness of local opportunities where students can continue to grow their science learning (museums, magnet schools, science fair, etc.) (all)	• Occasional instances of shutting down sensemaking (Caroline) • Replication of a guest/host hierarchy in the classroom (Amanda, Steve, to an extent Sandra)	• Students used their learning to think critically but not to develop a critical lens • No overt discussion or critique of the sociopolitical context of learning • No opportunities to address marginalizing school and life experiences to affect change
Belonging/ culturally relevant caring (high frequency across teachers, both supporting and undermining)	• Welcoming/calling on students by name (Caroline, Amanda) or by an academic title such as "scholars" or "learners" (Sandra) • Identifying successful strategies and thought processes, explaining the purpose of doing science (Caroline) • Connecting student interests to a variety of careers, acknowledging a variety of career interests (Caroline) • Using activities that promote teambuilding and collaboration through roles and norms (Caroline) • Modeling positive self-talk, including acknowledgement that science can be difficult (Caroline, Amanda) • Acknowledging students who have been absent, hurt, sick, etc. and making sure that they feel like they can resume participation (Caroline, Amanda)	• Using controlling language to dictate students' movements and define acceptable participation (Amanda) • Frequent invocation of specific behaviors as a condition for participation in class (Amanda, Steve) • Inclusion of students with language differences rather than an equity- or justice-focused approach (Amanda; Steve to an extent)	• Few culturally-situated references; lack of acknowledgment of students' heritage and goals • No reference to student rights; very little reference to implicit and explicit goals of the educational system

Table 7. *Supporting and undermining behaviors for Caroline*

Lesson	Clusters of supporting behavior	Clusters of undermining behavior
Lesson 1: Chemical vocabulary: using video and reading to support a prior card sort to define atoms and elements. **Overall Coding:** *High* due to consistent use of supports that promote belonging, position students as knowledge generators; few to no undermining examples.	*Positioning students as knowledge generators:* Uses explicit routines and strategies to help students work together. Frequent use of phrases such as "lean in" and "put your heads together."	*Positioning students as knowledge generators:* N/A
	Eliciting, valuing, and leveraging FOK: N/A	*Eliciting, valuing, and leveraging FOK*: N/A
	Encouraging use and sharing of student language: Explicit discussion of why it is important to have consensus about language and vocabulary as a class.	*Encouraging use and sharing of student language:* Brief instances of potential shutting down of sensemaking through facilitation: "Does anybody disagree with [student]?" and 'Who disagrees with her?" However, this could also be seen as promoting critical lens (see discussion).
	Valuing student experience as evidence: Makes connections to student interests outside of class and shows familiarity with students' interests. "I heard somebody say as soon as they saw what she was using for those building blocks, what did those building blocks remind you guys of?"	*Valuing student experience as evidence:* N/A
	Promoting critical lens to solve problems: Students comment on one another's ideas, providing the opportunity to evaluate ideas together.	*Promoting critical lens to solve problems:* N/A
	Belonging/culturally relevant caring: Use of explicit instruction about classroom routines to support students in understanding educational goals and how the classroom should work.	*Belonging/culturally relevant caring*: N/A
Lesson 2: Physical and chemical changes: how to identify signs of chemical change. **Overall Coding:** *Medium-High* due to use of strategies across several categories with brief undermining examples	*Positioning students as knowledge generators:* N/A	*Positioning students as knowledge generators:* N/A
	Eliciting, valuing, and leveraging FOK: Relating chemical change to phenomena that students are familiar with: ice melting, hair dying.	*Eliciting, valuing, and leveraging FOK:* Shuts down some student sensemaking/experiences when signs of a physical and chemical change are unclear (e.g., color change).
	Encouraging use and sharing of student language: Asking students to listen to one another's perspectives and words.	*Encouraging use and sharing of student language:* Brief instances of undermining expression of student ideas and language: Use of phrasing such as "Who wants to disagree with [Student A]?" without encouraging Student A to articulate their reasoning/continue in shared sensemaking

Table 7 (cont'd)

	Valuing students' experience as evidence: As noted above under FOK, students' experiences with accessible phenomena form the basis for conversation.	*Valuing students' experience as evidence: N/A*
	Promoting critical lens to solve problems: N/A	*Promoting critical lens to solve problems:* N/A
	Belonging/culturally relevant caring: Acknowledging student interests, ensuring all students are understanding, asking students to support one another as teammates while she facilitates/supports: "And when we're going to do the investigation, each one of you and your lab groups is going to have a role for me… I'm your facilitator and I walk around the room."	*Belonging/culturally relevant caring*: N/A
Lesson 3: CER: Has chemical change occurred? Making a claim about lab data and whether a chemical change occurred. **Overall Coding:** *Medium* due to consistent use of strategies that promote student belonging and continual validation of student ideas even in the face of struggle	*Positioning students as knowledge generators:* Validates the difficulty of doing science, communicating high expectations in the face of challenging topics and work. "I'm just curious, how many of you are finding this a little challenging to do? Okay, that's honesty. Thank you, [Student A]. Some of you found it easy to do. Let's try to help [Student A]. [Student B], what did you come up with for a claim…?"	*Positioning students as knowledge generators:* Some use of controlling language such as "I want you to" or "I need us to".
	Eliciting, valuing, and leveraging FOK: N/A	*Eliciting, valuing, and leveraging FOK:* N/A
	Encouraging use and sharing of student language: N/A	*Encouraging use and sharing of student language*: N/A
	Valuing students' lived experience as evidence: N/A	*Valuing students' lived experience as evidence*: N/A
	Promoting students' critical lens to solve problems: N/A	*Promoting students' critical lens to solve problems*: N/A
	Belonging/culturally relevant caring: Greeting students by name, asking students to identify resources that are helpful, ensuring that everyone has the chance to speak, working through challenging content as a team. Shows clear awareness of students who have been absent and goes out of her way to make sure they have opportunities to catch up.	*Belonging/culturally relevant caring*: N/A

Table 7 (cont'd)

Lesson 4: Preparation for culminating project on chemical change to support a project; discussion of magnet school visit **Overall Coding:** *Medium-High* due to clear and consistent validation of a variety of hopes and dreams. Less variety of strategy use because class period is monopolized by discussion of high schools and careers.	*Positioning students as knowledge generators:* N/A *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence*: N/A *Promoting students' critical lens to solve problems*: N/A *Belonging, culturally relevant caring:* Acknowledges a wide range of aspirations within and outside of science during her discussion of magnet schools and high school programs that support a variety of different types of learning: "Thank you for allowing me to talk to you guys about that because I want you guys to be excited about what your—where your futures are going and to start thinking about it."	*Positioning students as knowledge generators:* Brief interaction where teacher acknowledges outside research but interrupts without acknowledging a nuanced question that a student was curious about with indicator solutions. *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence*: N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring*: N/A

Table 8. *Supporting and undermining behaviors for Amanda*

Lesson	Clusters of supporting behavior	Clusters of undermining behavior
Lesson 1: Chemical vocabulary: defining atoms, molecules, and elements **Overall Coding:** *Medium Low* due to frequent use of controlling language which undermines belonging. Some use of intentional questioning strategies to support student thinking	*Positioning students as knowledge generators:* Uses strategies such as asking students "What do you wonder?" to get them to identify prior knowledge. Shows flexibility of representation and lets students choose which kinds of visual models make the most sense to them. *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: Asking students to generate shared definitions and concepts. *Valuing students' lived experience as evidence*: N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring*: Calls on students by name, discusses student birthdays as students come in.	*Positioning students as knowledge generators:* Near-exclusive use of curricular materials as the driver of class structure. "You have a paper, you look down here with your paper … because you're gonna be filling out that paper." *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence:* In planning, primarily relies on examples and strategies from packets. *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring.* Controlling behavior/language: Enforcing quiet and stillness in the classroom, as well as nonverbal cues to make students sit down (eyebrows, body language). "Why are you up?" "I hear an awful amount of noise that I don't think I should have." "This is what I want you to do." "I'm your teacher, this is what I do. So I made a whole PowerPoint just on how to help you. So this is what I want you to do."
Lesson 2: Chemical change: how to identify signs of chemical change **Overall Coding:** *Medium low* due to frequent use of controlling language. As with the prior class, some use of intentional scaffolding to keep track of student thinking progressions.	*Positioning students as knowledge generators:* Uses probing questions such as "What do we still need to know to figure out our problem? What are we figuring out right now?" to assist students in keeping track of their thinking and ideas. Guides students in capturing observations and trying to use inductive reasoning to generate definitions. "I used to think this, but now I know this. Look how far I've come." *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A	*Positioning students as knowledge generators:* Undermines student belonging by framing class as filling out worksheets: "Tell me what you think it is that we're supposed to be doing on that worksheet." *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A

Table 8 (cont'd)

	Valuing students' lived experience as evidence: N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring*: Compliments students on progress "I like the way you did that."	*Valuing students' lived experience as evidence*: N/A *Promoting students' critical lens to solve problems*: N/A *Belonging:* Calls out students by name when misbehaving, uses dominating body language to enforce student behavior.
Lesson 3: Chemical change lab: searching for evidence of chemical change **Overall Coding:** *Medium* due to opportunities for autonomy in carrying out the experiment.	*Positioning students as knowledge generators:* Frames failure as a part of learning. Anticipates possible problems to guide students through a procedure while allowing them autonomy as to how to carry out the experiment, making herself available to assist. *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence*: N/A, although the lesson topic relies on a lesson level phenomena that all students have access to. *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* Welcoming students by name, calling on students by name frequently, calling them awesome.	*Positioning students as knowledge generators:* Frames class goals in terms of completing packets. "I need warm ups out. I need these packets out." *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence*: N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* Power struggles with students about appropriate behavior; makes participation contingent on relying on narrow rules. "Hey, what's the rule about horseplay in the lab? Not so funny. Okay. Yeah. You'll be thrown out of the lab, and you will not be allowed to partake in any other labs for the rest of the year."
Lesson 4: Using observations of properties and characteristics of various substances to classify them **Overall Coding:** *Low* due to repeated negative framing and ongoing power struggles with disruptive students.	*Positioning students as knowledge generators:* Encouraging students to engage in science like scientists to draw conclusions; repeated encouragement to "think like scientists" and use precise language to describe things in the natural world. *Eliciting, valuing, and leveraging FOK:* N/A	*Positioning students as knowledge generators:* Students all proceed through lab at more or less the same pace; teacher-directed observations with predetermined outcomes. *Eliciting, valuing, and leveraging FOK:* N/A

Table 8 (cont'd)

Encouraging use and sharing of student language: Attributes specific ideas to students, highlights examples of strong use of scientific terminology.	*Encouraging use and sharing of student language*: N/A
Valuing students' lived experience as evidence: N/A, though the lesson provides access to a lesson-level phenomenon that all students have access to (observations of household substances)	*Valuing students' lived experience as evidence*: N/A
Promoting students' critical lens to solve problems: N/A	*Promoting students' critical lens to solve problems*: N/A
Belonging/culturally relevant caring: Reinforcement that students are acting as scientists.	*Belonging*: Power struggles with disruptive students. "I need you to take your hat off. And I need you to quit playing around. I'm over it. I have enough to deal with in this class, I don't need you making it worse."

Table 9. *Supporting and undermining behaviors for Sandra*

Lesson	Clusters of supporting behavior	Clusters of undermining behavior
Lesson 1: Definitions: matter/"stuff", physical versus chemical properties, chemical change **Overall Coding:** *High* due to consistent use of strategies that position students as knowledge generators and continual application of strategies to show students that they are scholars/ scientists. Few to no undermining behaviors.	*Positioning Students as knowledge generators:* Uses the curriculum to guide class discussion but allows students autonomy to figure out the lab portion and then reconvene during discussion. Uses open ended questions to get students thinking: "Who would like to elaborate?" "What other examples do you have?" "Why is it important that…?" "How are you going to…?" *Eliciting, valuing, and leveraging FOK:* Some examples in discussion—Kool Aid and cooking—may be seen as FOK, but are not reflective of deep culture *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence:* Students generate and comment on common examples of chemical change: cooking, Kool Aid, glass being made from sand, paper being made from trees. *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* calls on students by name, identifies herself as a learner alongside students. "Good afternoon my esteemed students." Checks in on learning progress: "Let's get a thumb check on time." Praises student with highest GPA in class: "as engineers, you're recognized for the quality work that you do. You get raises, you get bonuses, and your job recognizes you."	*Positions students as knowledge generators:* does not validate correctness of contributions or ask students to build upon one another's ideas (very slight) *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence*: N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring*: N/A
Lesson 2: Solubility, mixtures, lab on solubility of fat and soap in oil in water **Overall Coding:** *Medium* due to supports for student knowledge generation and the opportunity for students to come up with examples in discussion. A few minor undermining examples in relation to student misbehavior.	*Positioning students as knowledge generators:* Students do their own investigation, generate their own procedure, and Sandra allows for mistakes to happen. Sandra keeps track of student questions and retires questions when students have come to a consensus about the answer to it. "As we have been working in this unit, I took a look at your driving question board, and I pulled off some questions that I think maybe we're able to find answers to." *Eliciting, valuing, and leveraging FOK:* N/A	*Positioning students as knowledge generators: N/A* *Eliciting, valuing, and leveraging FOK:* N/A

Table 9 (cont'd)

	Encouraging use and sharing of student language: Keeps track of student-generated questions and uses them as the basis for discussion later. *Valuing students' experience as evidence*: Encourages students to generate examples of changes in and outside of their homes, students bring up examples from cooking, handwashing, saltwater, and items that shouldn't dissolve or be soluble in rain or water such as paint or metals. *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* Greets/acknowledges students by name, refers to them as "scholars"; "Missed you yesterday", "I know you are prepared." Frames learning as progress towards answering shared questions.	*Encouraging use and sharing of student language:* N/A *Valuing students' experience as evidence-* N/A *Promoting students' critical lens to solve problems:* N/A *Belonging/culturally relevant caring:* Enforcement of rules "Excuse me. As I told my other students yesterday, don't get written up for destruction of school property. Even though you're using an eraser, you are destroying my tables." (Students blame one another.) "Oh I watched both of you… I'm about to take a picture and show it…"
Lesson 3: Evidence for a chemical change, using various chemical properties to compare materials **Overall Coding:** *Medium low* due to scripted outcomes and reliance on packets to frame learning; positive reference to examples from outside class in discussion	*Positioning students as knowledge generators:* Asks for examples of chemical change in or out of home, students fire, foods going from raw to cooked. They contrast this to Kool Aid, salt being mixed with baking soda, and other experiences from class or from students' daily lives. Students decide what data they need to collect and discuss as groups. "It's just like making the cake. All right, let's take from our reading. You had eggs and you had flour and butter and sugar. Those are your reactants because those are the old substances you start with. Once the chemical reaction takes place is what this arrow is showing us." *Eliciting, valuing, and leveraging FOK*: N/A *Encouraging use and sharing of student language*: N/A *Valuing students' experience as evidence:* N/A *Promoting students' critical lens to solve problems:* N/A	*Positioning students as knowledge generators:* Frames learning as completion of the packet. Reliance on packet to have students come to a predetermined outcome about the burning of magnesium. Class jumps from one task to another without clear progression from one activity to another in relation to student thinking. *Eliciting, valuing, and leveraging FOK*: N/A *Encouraging use and sharing of student language*: N/A *Valuing students' experience as evidence:* N/A *Promoting students' critical lens to solve problems:* N/A

Table 9 (cont'd)

	Belonging/culturally relevant caring: Relating current content to making cakes and things they have done in math. "What questions do you have so far?"	*Belonging/culturally relevant caring*: N/A
Lesson 4: Calculating density, additional examples of chemical vs. physical change **Overall Coding:** *Medium* due to strong facilitation of discussion; reliance on packet as the purpose of class undermines student knowledge generation	*Positioning students as knowledge generators:* Asks students to listen to one another; helps build on one another's ideas.	*Positioning students as knowledge generators:* missing pages in packets confuse students as they get set up for the day. Scripted outcomes occasionally undermine ability to develop student reasoning. Transitions from one activity in the packet to another sometimes feel abrupt and fail to build on one another: "We've got a lot to cover, let's move on" "There's so much talking here some of you have no idea what I'm talking about."
	Eliciting, valuing, and leveraging FOK: N/A	*Eliciting, valuing, and leveraging FOK*: N/A
	Encouraging use and sharing of student language: Attributes ideas to students	*Encouraging use and sharing of student language*: N/A
	Valuing students' experience as evidence: N/A	*Valuing students' experience as evidence:* N/A
	Promoting students' critical lens to solve problems: N/A	*Promoting students' critical lens to solve problems:* N/A
	Belonging: Asks students to listen to one another. "Who would like to bring us up to date? How can we tell if a chemical reaction occurred or not?" "What questions do you have?" "If you want to call somebody to help you, that's ok." "Did you hear what he said over here? … When I call on you and you give a response, they're going to do the same courtesy with you."	*Belonging*: N/A

Table 10. *Supporting and undermining behaviors for Steve*

Lesson	Clusters of supporting behavior	Clusters of undermining behavior
Lesson 1: Observations of changing substances: copper chloride and aluminum foil **Overall Coding:** *Medium* due to varied supports for student thinking and observations; a few behaviors that undermine belonging.	*Positioning students as knowledge generators:* "Write down questions in your table. I heard one good question already." *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: Writes down students' observations, repeats their observations *Valuing students' lived experience as evidence:* N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* Procedures and expectations clear, calls on students by name and enforces that they listen to one another's voices. "Don't interrupt her." "Listen to [Student A]." Calls on students by name.	*Positioning students as knowledge generators:* N/A *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence:* N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* Use of identity to describe people: "Religious diversity people" are absent. Gendered language: "Girls, I should see you with hair ties in." Ties grade to tight behavioral expectations: "I'm going to be grading your lab techniques, so every time I have to tell you to put on safety goggles, I'm taking a point off. Every time I have to correct you from not following directions, I'm taking a point off. Any time I see you off task, I'm taking a point off."
Lesson 2: Defining properties-comparing & calculating density of objects. **Overall Coding:** *Medium* due to varied supports for knowledge generation and sensemaking observations; a few behaviors that undermine belonging.	*Positioning students as knowledge generators:* Students are invited into sensemaking conversations about density. Steve relates conversation to common experiences such as overflowing bathtub. Multiple examples of sensemaking and authentic conversation. Helps students make sense of lab results and interpret observations in context. *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: Speaks to a student in Spanish "¿Como estas? ¿asi asi?" *Valuing students' lived experience as evidence:* N/A	*Positioning students as knowledge generators:* All students must come to a predetermined conclusion or follow a predetermined instructional sequence: following steps exactly rather than designing their own protocols. *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: N/A *Valuing students' lived experience as evidence:* N/A

Table 10 (cont'd)

	Promoting students' critical lens to solve problems: N/A *Belonging/culturally relevant caring:* "I like how you're doing that, with one person responsible for directions?", calls on students by name.	*Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* Engages in comparison between groups. "You need to measure the mass first. (indicating another group) oh they did it right." "Everyone else is recording data except you." Use of sarcasm and controlling language.
Lesson 3: Applications of density and conceptual clarification **Overall Coding:** *Medium-low* due to less varied use of sensemaking strategies and the frequency of shutting down of "incorrect" sensemaking.	*Positioning Students as knowledge generators:* Discusses limitations of procedures in getting accurate results, revisits strategies and observations for students to interpret. "What does learning about density have to do with learning about old stuff and new stuff?" "Which one do you think is important for telling the difference between the two? Uses student answers and reasoning to model filling in the do-now. *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: Acknowledges skills of teacher who does not speak Spanish but who helps ELL students understand concepts. *Valuing students' lived experience as evidence:* Incorporates students' stories about inhaling helium and zeppelins, and connects their anecdotes to curricular content. *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* See above notes about validating contributions of ELL teachers in multilingual environment. Calls on students by name.	*Positioning Students as knowledge generators:* Frames learning as completion of the packet: "We're done with lesson 4.. I know you're excited by this… but you'll love them when it comes to the test." Encourages some sensemaking but is abrupt with corrections during episodes. Shuts down student thinking rapidly when students give incorrect answers. (Occurs repeatedly) *Eliciting, valuing, and leveraging FOK:* N/A *Encouraging use and sharing of student language*: Shuts down student thinking when imprecise terms are used or when students confuse two concepts. *Valuing students' lived experience as evidence:* N/A *Promoting students' critical lens to solve problems*: N/A *Belonging/culturally relevant caring:* Some instances of controlling language.

Table 10 (cont'd)

Lesson 4: Burning as a chemical reaction **Overall Coding:** *Medium* due to varied supports for student sensemaking; brief instances of undermining belonging.	*Positioning Students as knowledge generators:* Asks students to debate the essential question from the Rumplestiltskin story, encourages them to make sense of observations that are accessible to all. "What did [Student] and [Student B] say we needed to know [in order to prove that something is a chemical reaction]?" "What does that remind you of?" "You think a chemical reaction happened; how do you know?"	*Positioning Students as knowledge generators:* N/A
	Eliciting, valuing, and leveraging FOK: N/A	*Eliciting, valuing, and leveraging FOK:* N/A
	Encouraging use and sharing of student language: Repeats students' observations, attributes ideas to students, gives them feedback when they come up with good/appropriate descriptive words, "let's see who was paying attention to what [Student A] said"	*Encouraging use and sharing of student language*: N/A
	Valuing students' lived experience as evidence: N/A	*Valuing students' lived experience as evidence:* Student has done one of Steve's demos at home with his dad; Steve discusses discrepant results but insists that the student made an error rather than engaging in curiosity about the results.
	Promoting students' critical lens to solve problems: N/A	*Promoting students' critical lens to solve problems*: N/A
	Belonging/culturally relevant caring: Calls on students by name, jokes and laughs with students, talks about how exciting magnesium is, acknowledges that a student was unable to generate an example because he was "on the spot"	*Belonging/culturally relevant caring:* Controlling language, "Stop, because I see people doing things wrong already." Student comes in late: "Where's your stuff? …so go get your stuff. You need a book, I don't know why you came to class without a book."

APPENDIX B: FIGURES

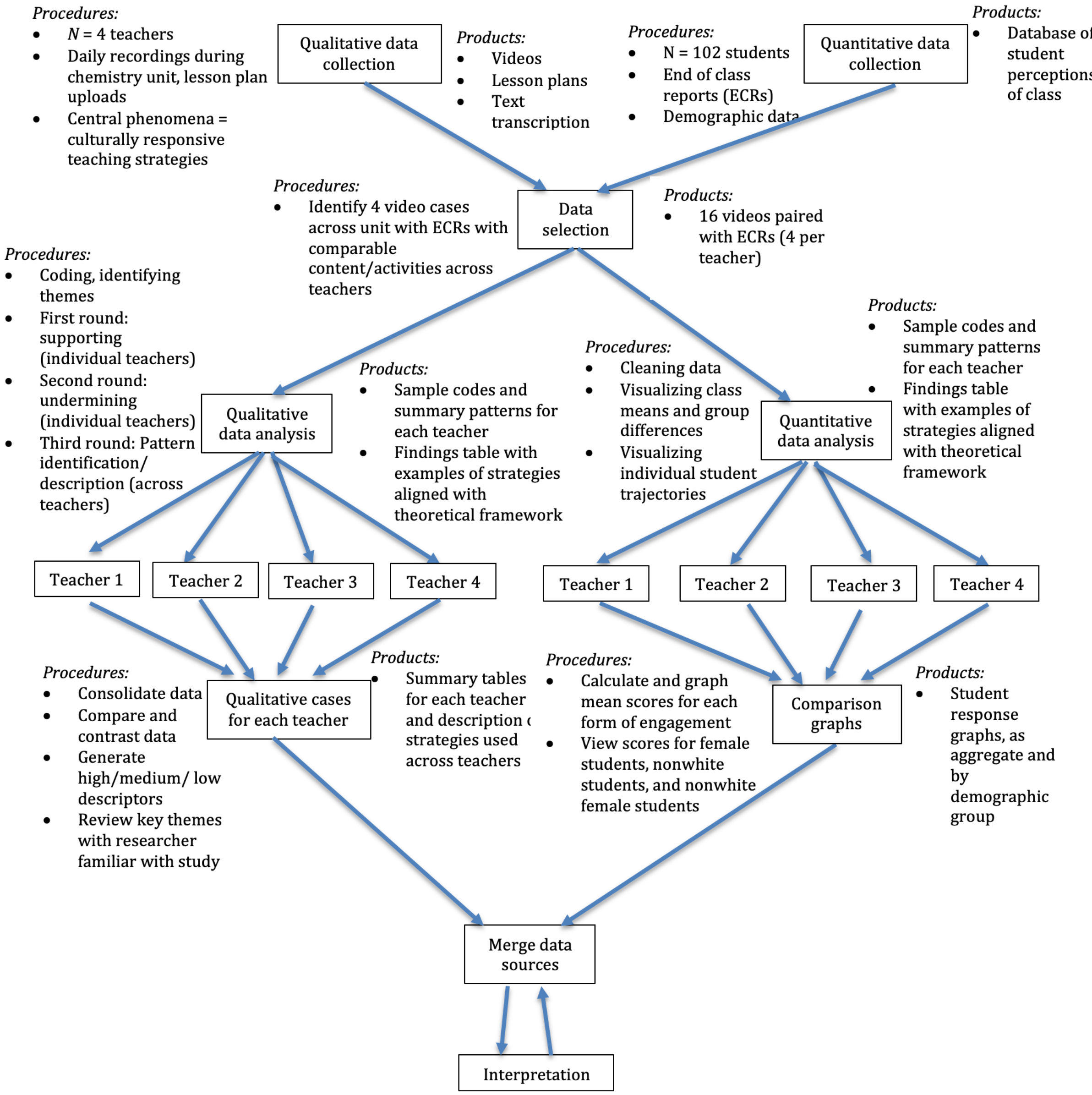

Figure 1. Study design

Note: Study designed using convergent mixed methods design (Creswell, 2015)

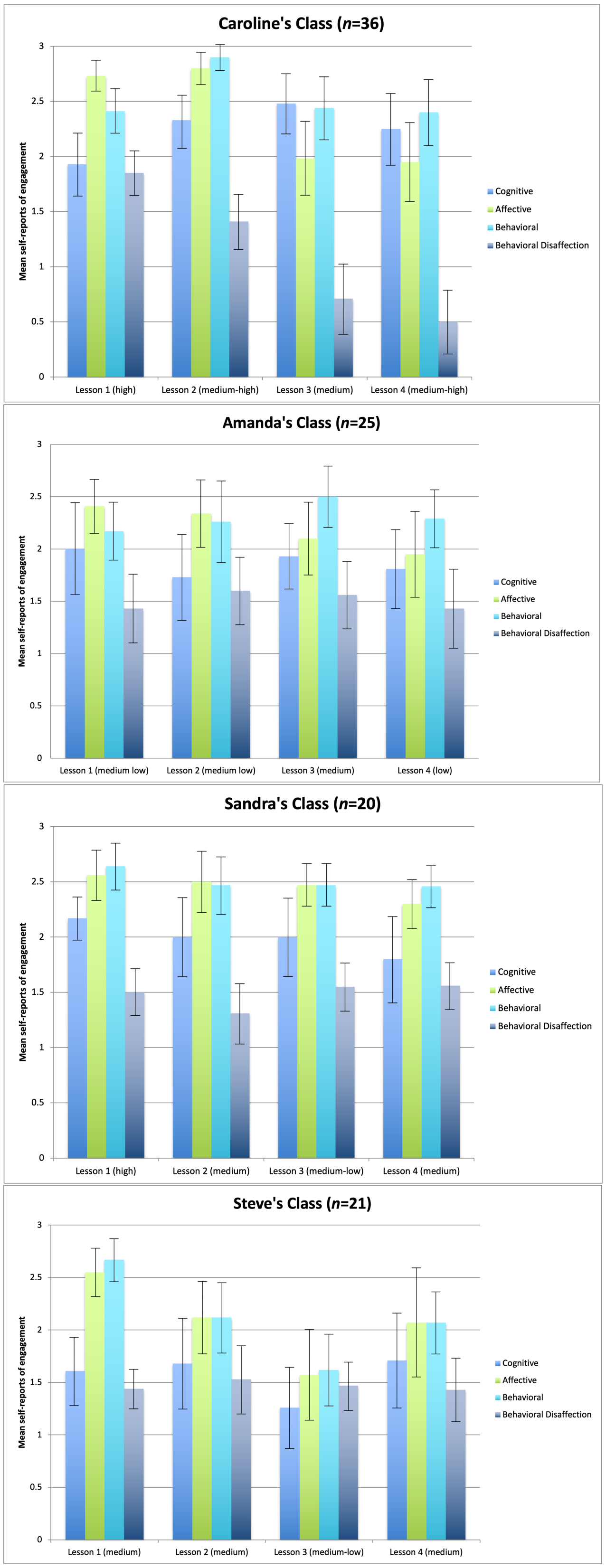

Figure 2. Mean engagement across lessons (0-3 Likert scale; error bars indicate SD for each lesson)

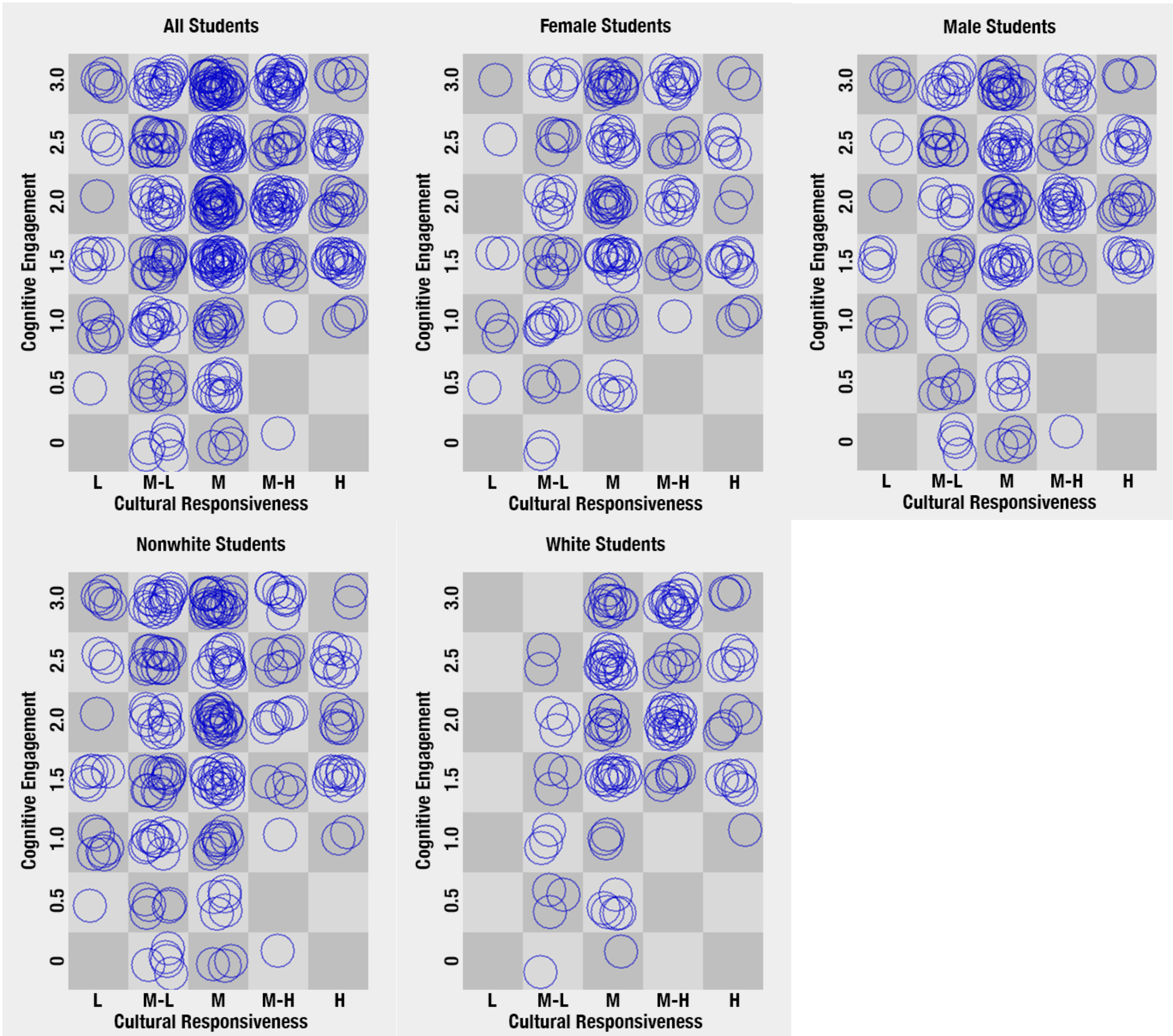

Figure 3. State space grid of student cognitive engagement and teacher cultural responsiveness

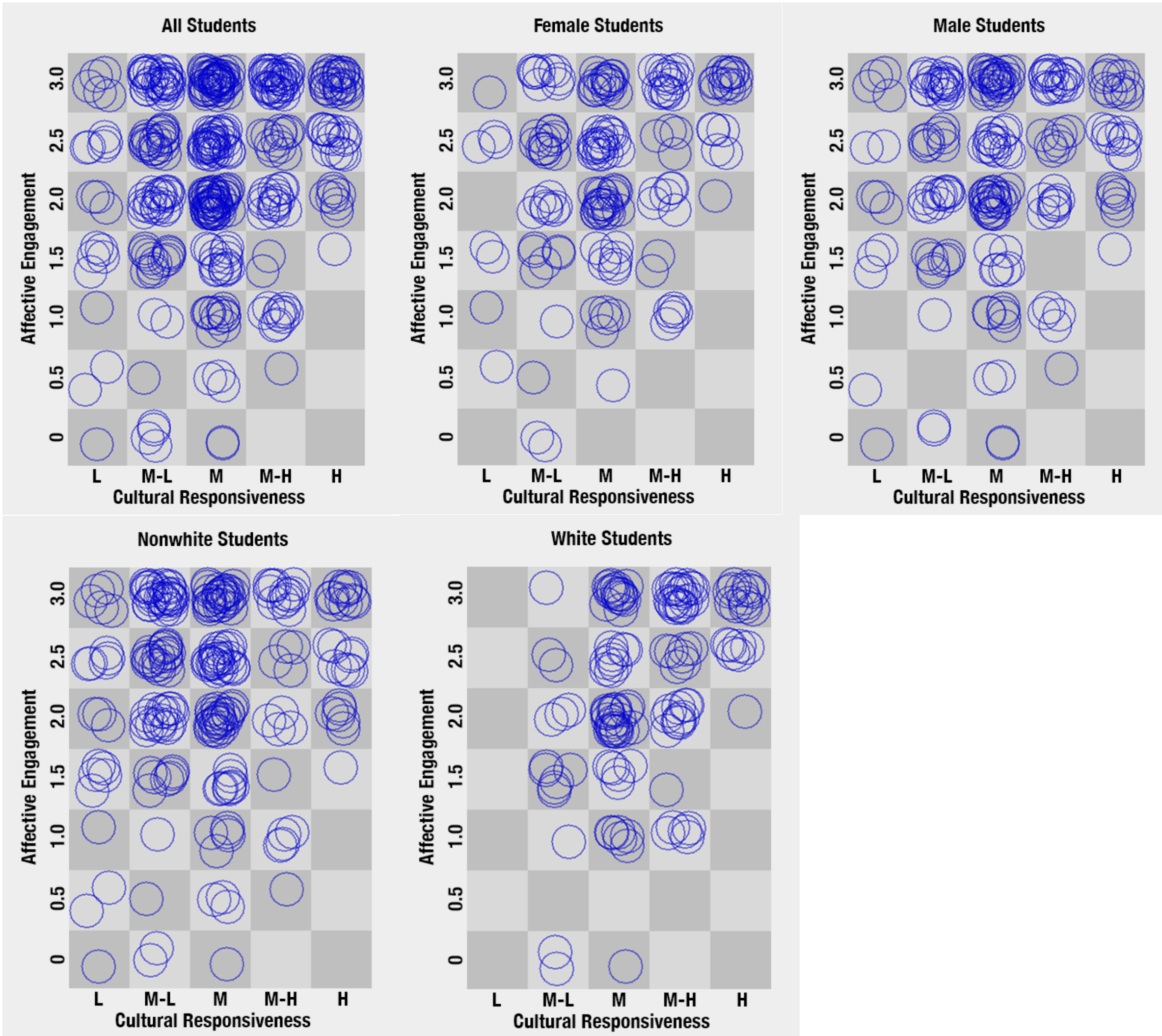

Figure 4. State space grid of student affective engagement and teacher cultural responsiveness

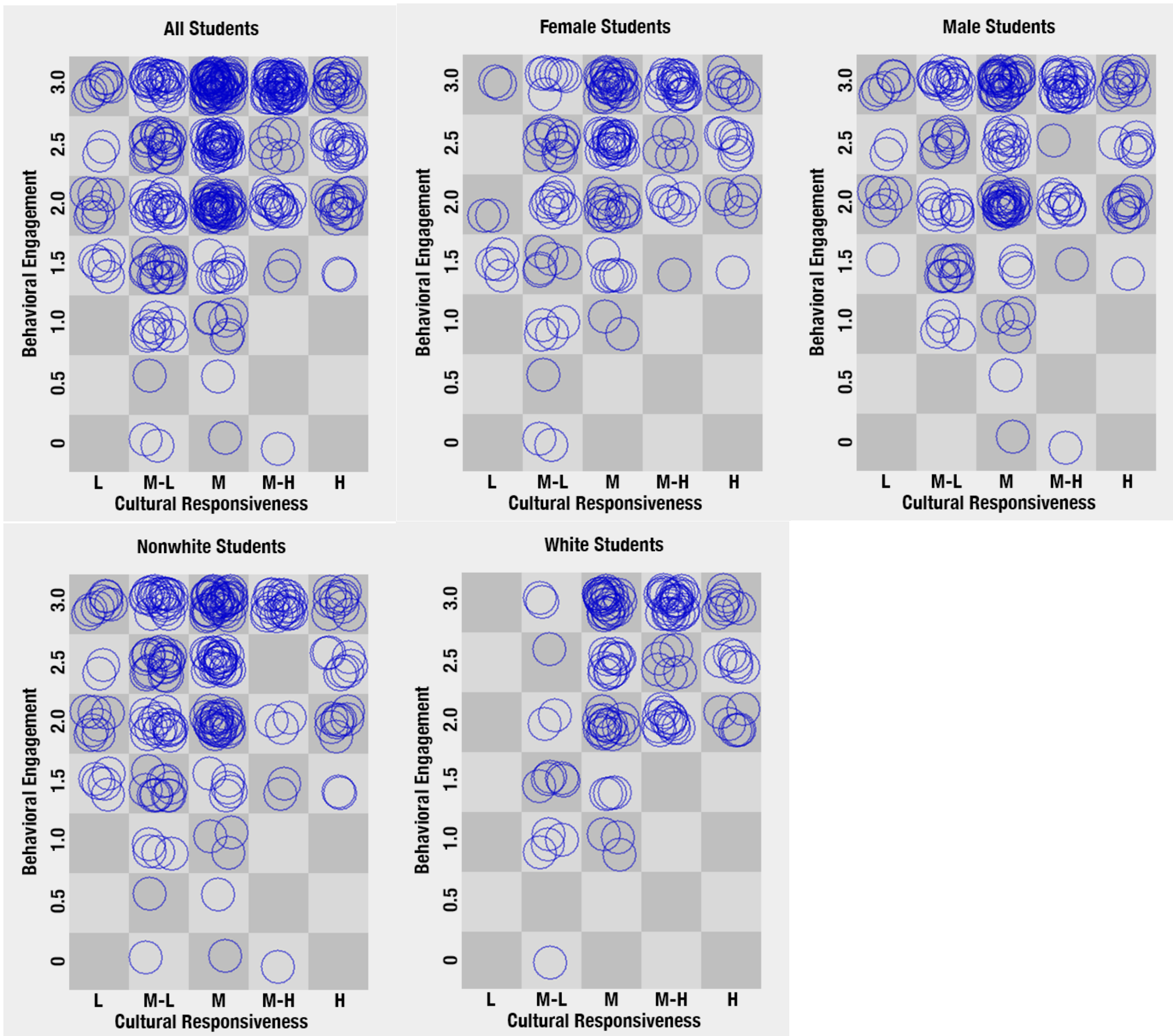

Figure 5. State space grid of student behavioral engagement and teacher cultural responsiveness

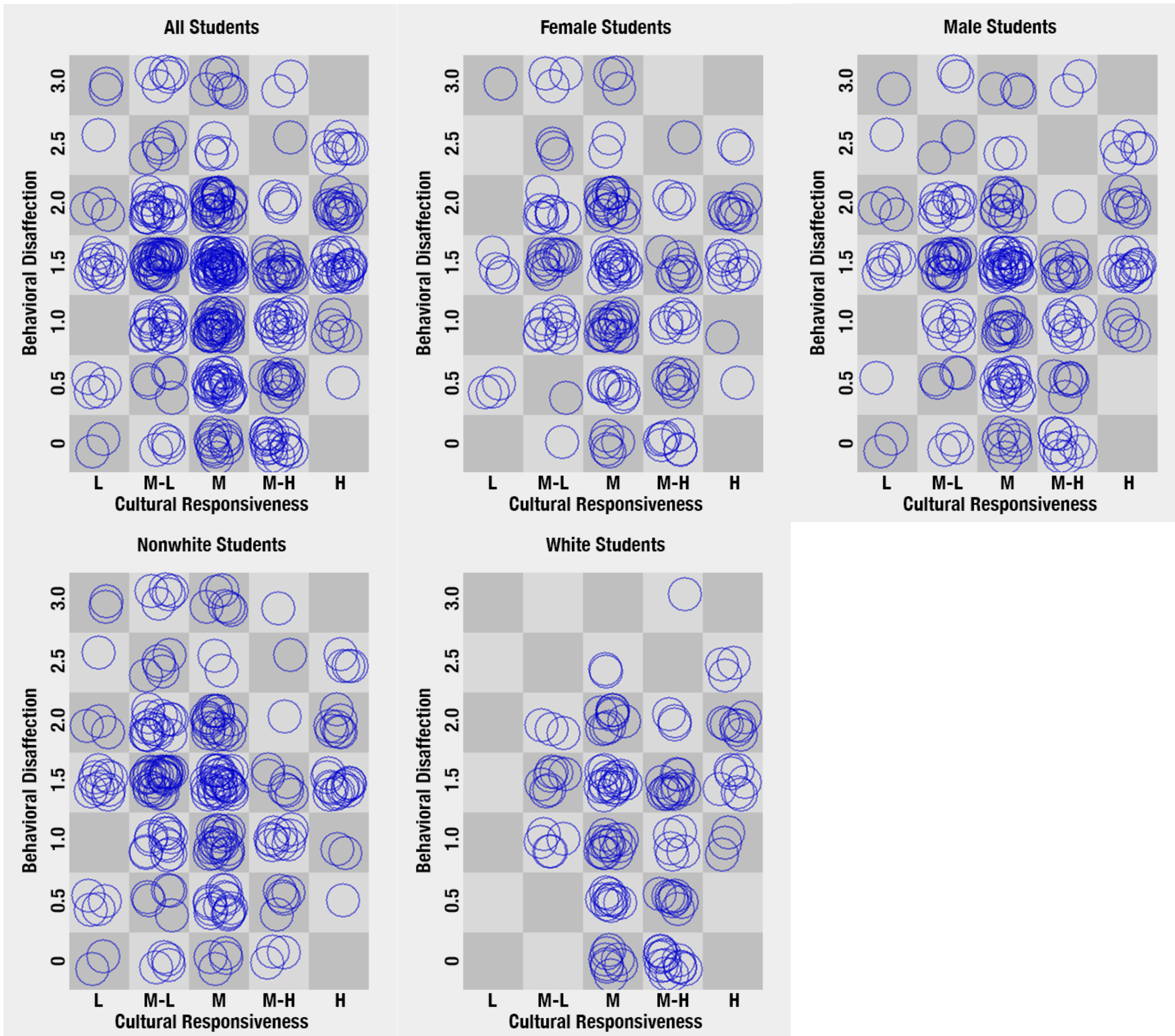

Figure 6. State space grid of student behavioral disaffection and teacher cultural responsiveness

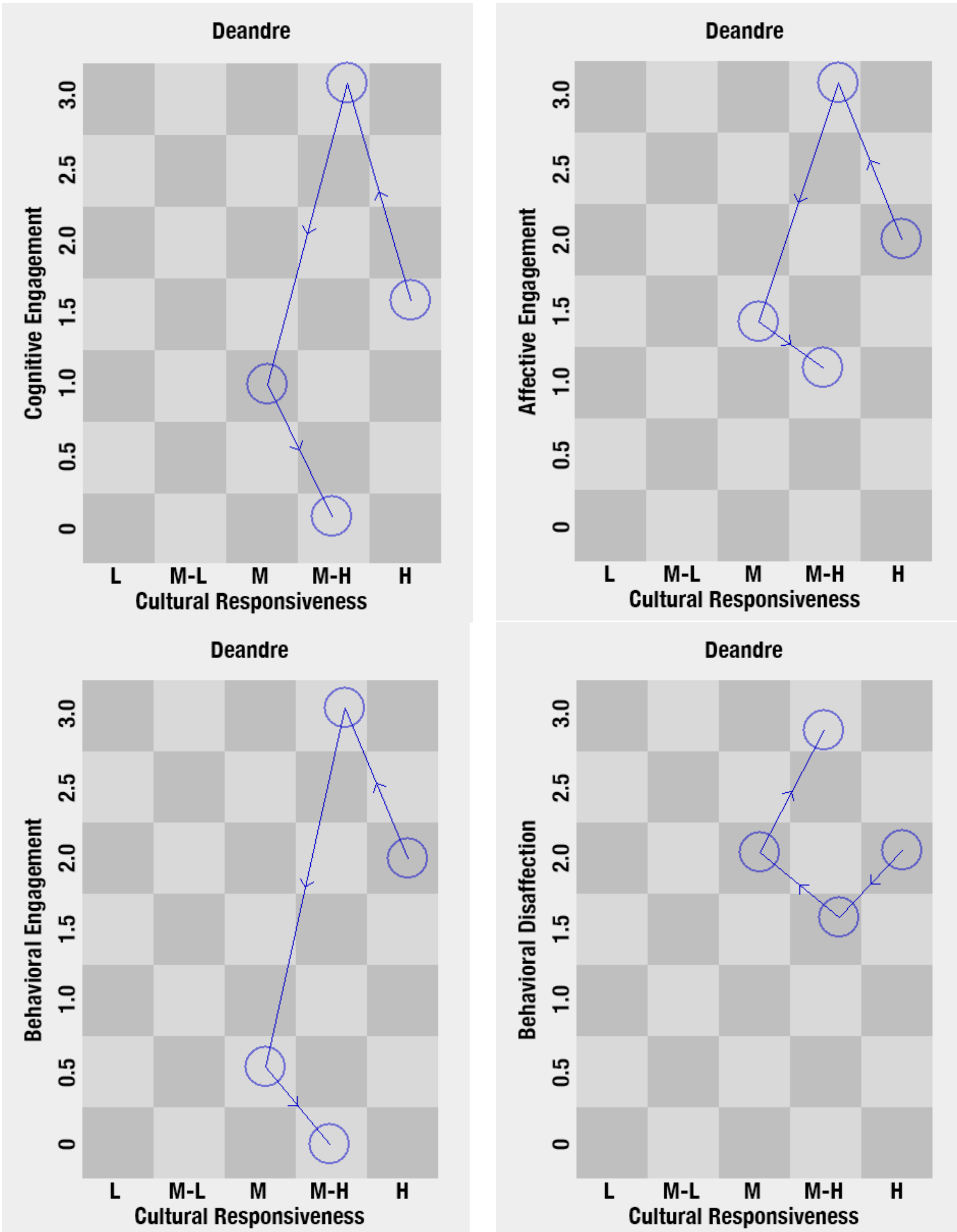

Figure 7. Deandre's class-level trajectories

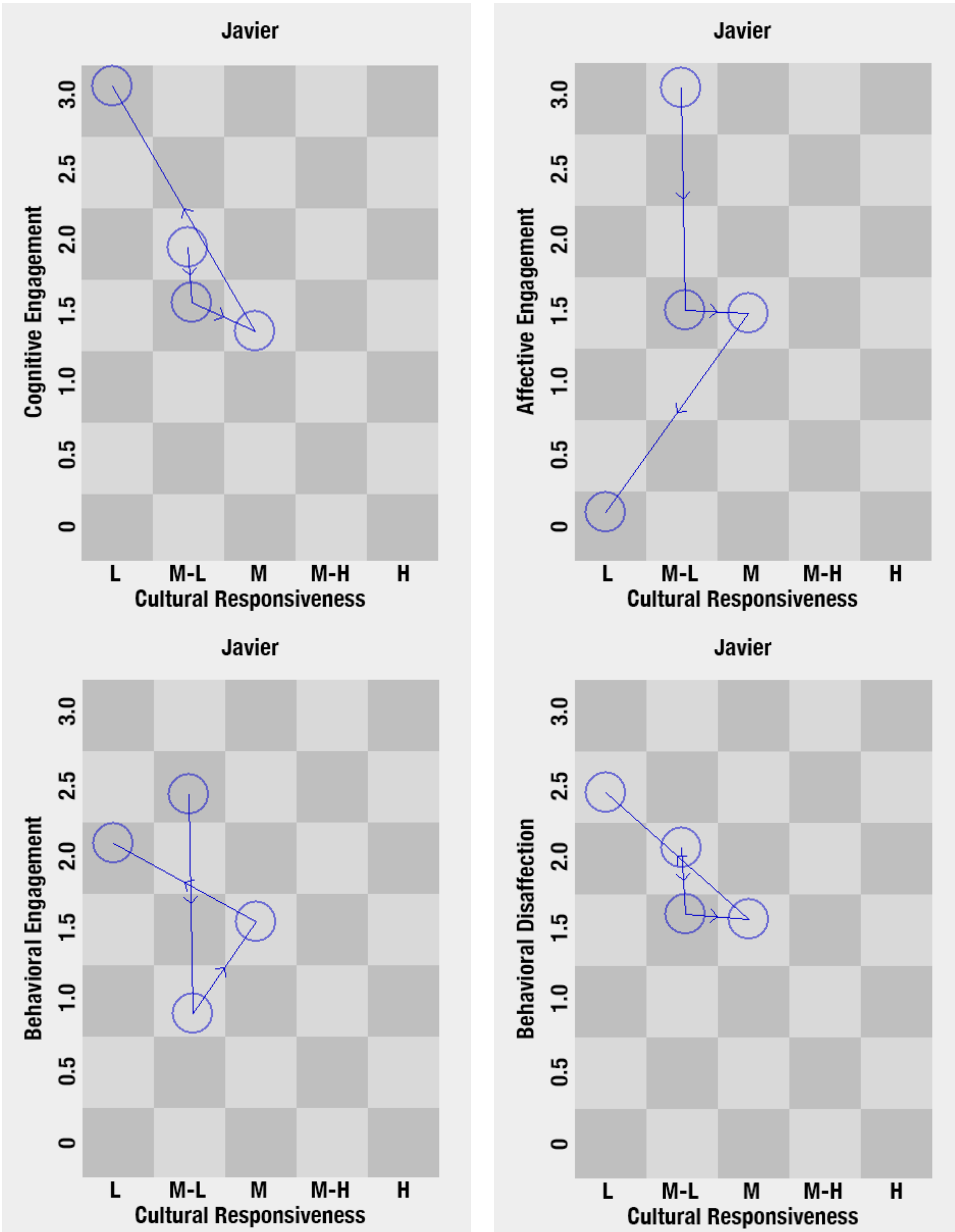

Figure 8. Javier's class-level trajectories

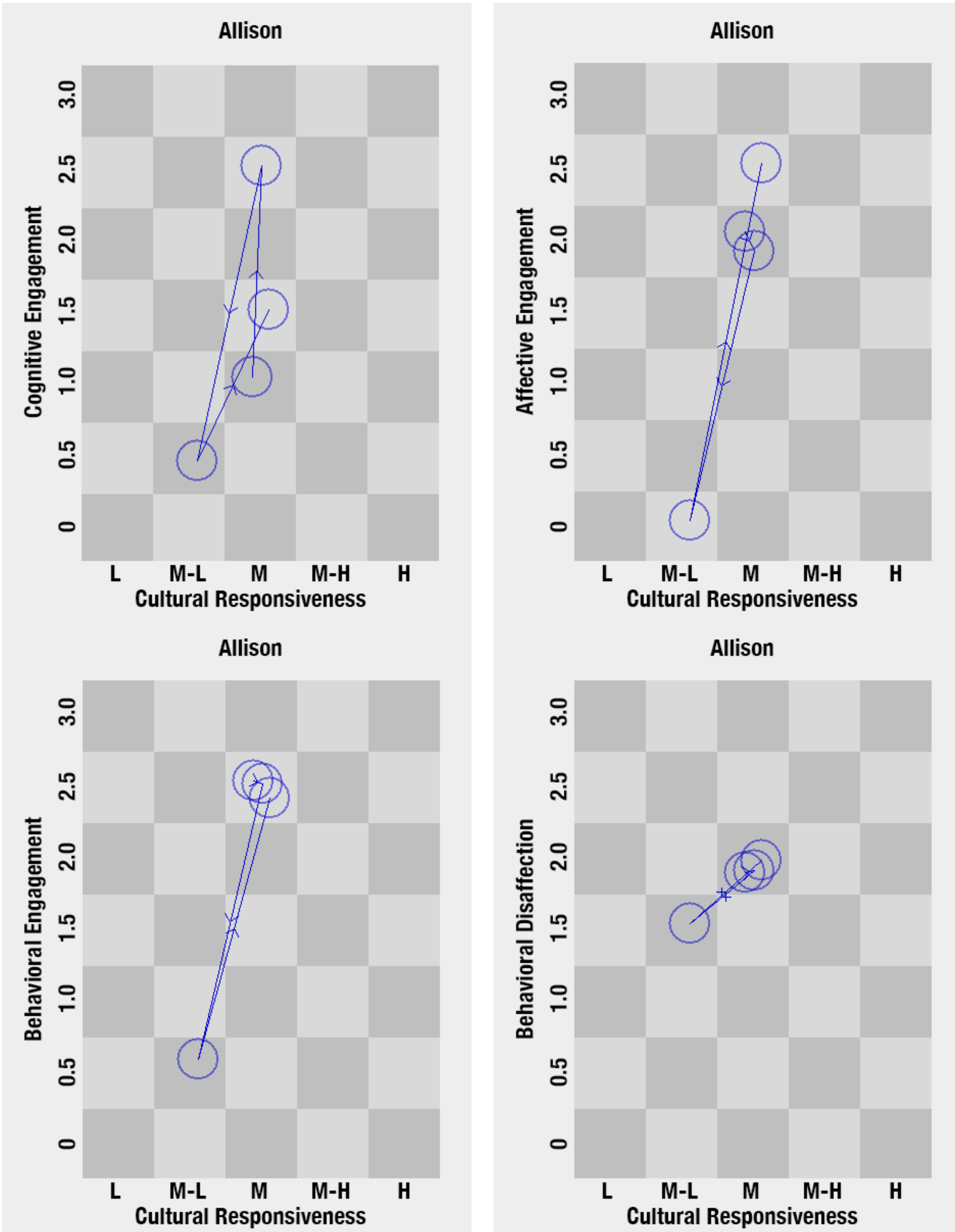

Figure 9. Allison’s class-level trajectories