Autonomy Support, Cultural Engagement Practices, Need Satisfaction, and Engagement Among Urban High School Science Students During the Onset of the COVID-19 Pandemic

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Abstract

Extensive research indicates that students are more engaged when teachers adopt autonomy supportive strategies. However, for racially and ethnically minoritized U.S. students, needs may be best supported when instructors incorporate cultural engagement practices. The current investigation examined relationships between diverse urban U.S. high school students' perceptions of science teachers' cultural engagement and autonomy supportive practices, psychological need satisfaction, and engagement in chemistry and physics classes during COVID-19 school restrictions. This study used a multi-wave survey design in which students reported on their perceptions of teacher practices, needs, and engagement over the course of four months. As predicted, perceptions of cultural engagement practices correlated with autonomy support. Structural equation models indicated that perceptions of cultural engagement practices predicted increased engagement via increased need satisfaction but only in the absence of autonomy support, which also predicted needs and engagement. However, moderator analyses indicated that relationships varied by gender. Specifically, cultural engagement practices predicted increased need satisfaction even after controlling for autonomy support among boys, but not girls. In contrast, autonomy support significantly predicted need satisfaction for both girls and boys. Implications for theory, future research, and practice are discussed.

Keywords: autonomy support, cultural engagement, teacher practice, self-determination, culturally-responsive and -relevant education, engagement, motivation, high school

Educational Impact and Implications Statement

This survey study demonstrates the critical importance of teaching practices that support autonomy and cultural relevance for racially and ethnically diverse urban U.S. high school science students' engagement. Results showed that feeling autonomous is a key mechanism through which culturally supportive teaching practices affect students' engagement in science, particularly among boys. Results highlight the importance of considering students' identities in science classrooms.

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From one course to the next, students will vary in their motivation, engagement, and learning. The extent to which teachers create a classroom environment that is intentionally supportive of motivation and engagement often explains variation. From a self-determination theory (SDT) perspective (Ryan & Deci, 2017), students will be more motivated and engaged, ultimately learning better, when teachers adopt strategies that support psychological needs, particularly strategies that support students' need to experience autonomy or the sense that behaviors emanate from the self and are congruent with one's values, goals, and interests (Patall & Zambrano, 2019). Extensive correlational, longitudinal, and experimental research has supported this proposition (Patall & Zambrano, 2019; Reeve & Cheon, 2021).

Alternatively, a collection of theories and research referred to collectively as culturally relevant and responsive education (CRRE) explicitly focuses on the racialized experiences of students of color to understand the classroom context in which students are most engaged and learn best (e.g., Aronson & Laughter, 2016; Banks, 1993; Gay, 2018; Ladson-Billings, 1995; López, 2017; Paris & Alim, 2014). From these perspectives, supportive classroom environments are those that explicitly consider students' experiences related to their race, ethnicity, communities, and culture to structure the content and facilitate learning. Extensive qualitative evidence has supported the benefits of CRRE for students' motivation, engagement, and learning (see Aronson & Laughter, 2016 for a review).

Despite some shared assumptions across CRRE and SDT perspectives (Kumar et al., 2018; Patall et al, 2026), there have been limited empirical attempts to understand how they

relate or synergistically support the motivation and engagement of diverse students. Although the SDT framework has been widely and successfully applied in education research to understand student functioning and provide guidance to educators, there has been limited attempts to specifically capture the racial, ethnic, and culturally rooted experiences of U.S. students of color or minoritized students in other countries within SDT conceptions of motivationally supportive instruction, (e.g., Cokley, 2015; Kumar et al., 2018; López et al., 2022; Yates & Patall, 2021). For racially and ethnically minoritized students, needs may be best supported when instructors extend their practices beyond autonomy support, which has not explicitly addressed issues of race and culture in its theorizing, to using cultural engagement practices that explicitly involve using diverse students' cultural realities, perspectives, and characteristics as vehicles for learning and engagement.

Likewise, although CRRE theory and research often cite the importance of various motivation relevant concepts (e.g., empowerment, agency, interest, competence, belonging, values, identity) as mechanisms by which CRRE supports learning, there has been little explicit theorizing and testing of psychological needs as a key mechanism. Given that extensive research across cultures has found needs to be critical to adolescent learning and well-being (e.g., Chen et al., 2015; Patall & Zambrano, 2019), psychological need satisfaction is a promising mechanism by which CRRE supports students' outcomes that remains to be tested.

Within this context, the purpose of the current investigation was to explore the relationships between racially and ethnically diverse urban U.S. high school science students' perceptions of their teachers' cultural engagement practices, autonomy support, need satisfaction, and engagement across two-timepoints during a 20-week academic semester that occurred during the onset of the COVID-19 pandemic. We situated this investigation in urban

U.S. high school physics and chemistry classes serving primarily students of color (e.g., primarily Latinx, Asian, and Black students) from modest income backgrounds, for whom research on the links between teachers' autonomy relevant practice and engagement has been limited and CRRE may be most relevant, and focused on adolescents, for whom gaining greater autonomy, agency, individuation, and independence are key developmental tasks (Eccles et al., 1993; Erikson, 1968). Moreover, to better understand heterogeneity, we explored whether the links between teachers' support and students' need satisfaction varied depending on the level of each practice, students' gender, and students' vulnerability to racial/ethnic stereotypes. Finally, although it was not planned, data collection for this study occurred during the onset of the COVID-19 pandemic, with early data collection occurring prior to school closures and later data collection occurring after the transition to remote online learning. The timing of this investigation in 2020 allowed us to explore the relationships between supportive practices, motivation, and engagement during a time (i.e., COVID-19 pandemic) of exceptional stress and disengagement.

Engagement and Autonomy Supportive Instruction

In educational settings, student engagement is a multidimensional construct that can be broadly defined as involvement in tasks or activities, including behavioral (e.g., attention, participation), emotional (e.g., positive affect), cognitive (e.g., regulation of learning), and agentic (e.g., attempts to collaboratively influence on instruction) components (Fredricks et al., 2004; Reeve, 2013). Engagement is a marker of students' positive functioning in the classroom, being a key mechanism through which learning occurs (e.g., Jang et al., 2012; Skinner et al., 2009). According to self-determination theory (SDT; Ryan & Deci, 2017), a macro-theory of human motivation, students' engagement is catalyzed by key psychological needs for autonomy

(e.g., sense that actions emanate from the self), competence (e.g., sense of mastery), and relatedness (e.g., sense of mutual caring with others). Thus, educational environments that support the satisfaction of these needs are considered higher quality (Jang et al., 2016; Patall et al., 2018b; Patall & Zambrano, 2019).

In particular, autonomy supportive teaching is a style of instruction marked by understanding and perspective-taking (e.g., Reeve & Cheon, 2021). The approach can include a variety of practices, all of which are meant to help students feel that their behavior reflects their own values and goals. Common autonomy supportive practices include offering choices, structuring activities around students' interests, providing meaningful rationales, or being open and responsive to questions and suggestions (e.g., Ahmadi et al., 2023; Patall & Zambrano, 2019; Su & Reeve, 2011). Extensive longitudinal and experimental evidence across a variety of settings, countries, and cultures suggests that teachers' autonomy support enhances students' experiences of need satisfaction and in turn, their classroom engagement (e.g., For a review, see Patall et al.,, 2026; Patall & Zambrano, 2019; Reeve & Cheon, 2021). In line with the heightened sensitivity to being treated with respect and afforded decision making opportunities during adolescence (e.g., Ruck et al., 1998), autonomy support seems to be particularly critical during this developmental phase (e.g., Katz et al., 2009). Results from this study will expand upon this body of evidence to show the effects of autonomy support on students' engagement during the onset of the COVID-19 pandemic, a time which marked the start of heightened stress and disengagement that has continued to persist (e.g., Malkus, 2025).

SDT scholars assert that the needs are universal, and thus, autonomy support will routinely have benefits for people from various backgrounds and cultures (Chen et al., 2015; Ryan & Deci, 2017). Although values that come from one's culture or community can assign

meaning and influence how interactions and educational practices are interpreted, any practice that ultimately leads to an experience of autonomy is expected to yield benefits for students' motivation, engagement, and learning (e.g., Reeve et al., 2018; Soenens et al., 2015). Despite SDT's widespread application in research with secondary school students across cultural contexts such as Korea (Cheon et al., 2020; Jang, 2009), China (Feng et al., 2019), Singapore (Caleon et al., 2016), Indonesia (Maluana et al, 2016), Spain (González-Peño et al., 2021), Russia (Chirkov & Ryan, 2001), Nigeria (Sheldon et al., 2009), Peru (Matos et al., 2018), and India (Sheldon et al., 2009), there is still limited evidence with diverse U.S. secondary student groups (e.g., for examples, see Connell et al., 1995; Froiland et al., 2016; Parker et al., 2021; Patall et al., 2018b; 2022; Wallace & Sung, 2017). The limited research that exists provides support for the benefits of autonomy support with students of diverse racial and ethnic backgrounds. Moreover, the emphasis on autonomy is consistent with key values of many communities of color and across cultures (e.g., Froiland et al., 2016; Karenga, 1989; Krys et al., 2022; Villalobos Solís et al., 2016). Nonetheless, there have been limited explicit attempts to integrate an understanding of their racialized and cultural experiences into the autonomy support framework, which are important considerations in the United States context and in other countries with racial and cultural diversity. Some research has shown the benefits of integrating SDT and critical racial or cultural perspectives in qualitative and cross-sectional research with high school and college students of color (Lopez et al., 2022; Zambrano et al., 2026). Lopez et al. (2022) and Zambrano et al. (2026) both found that race-reimaging traditional SDT constructs (i.e., basic psychological needs and autonomy support) to center and connect with students' cultures provided additional power for explaining the relationship between SDT constructs and other outcomes among racially and ethnically diverse students over and above the traditional

conceptualizations. This evidence suggests that effective support for engagement may entail combining or integrating autonomy support from the SDT perspective with a culture-based, race-focused, or justice-oriented framework for supporting motivation. SDT's failure to explicitly address the role of race, ethnicity, and culture in students' learning experiences presents an important opportunity to integrate cultural learning theories to better address the needs of all students, but particularly for marginalized minority students to better promote equitable outcomes. From cultural learning theory perspectives, culture and learning are inherently intertwined. Therefore, for autonomy supportive instruction to be effectively integrated with cultural learning theory, instruction must aim to align students' learning with their cultural identities and contextualize course content from multiple cultural perspectives.

Cultural Engagement Practices

Broadly, culturally-responsive and -relevant education (CRRE) frameworks emphasize the value of incorporating students' racial and cultural experiences into learning activities and curriculum to promote learning (Dickson et al., 2015; Gay, 2018; Ladson-Billings, 1995). While there are multiple frameworks related to this idea, including culturally responsive teaching, culturally relevant pedagogy, culturally sustaining pedagogy, multicultural education, and asset-based pedagogy, they all share the central goal of improving education for ethnically diverse students by embedding diverse cultural perspectives into the curriculum. Instructors that use CRRE approaches to instruction promote high expectations with caring, support student agency, decision-making, and self-regulation, incorporate cultural referents that are meaningful to students from their diverse cultural, racial, and social backgrounds, and engage students in critical reflection about society in order to empower them to take actions that benefit themselves and their community (e.g., López, 2016; Moses, 1997; Nieto & Booth, 2010). In particular,

CRRE has been proposed as a method for reducing racial and ethnic inequities in school experiences and success by explicitly leveraging and fostering students' cultural competencies and by validating students' backgrounds through inclusive course content that mirrors racially, ethnically, and culturally diverse students' lives (Kotluk & Kocakaya, 2018).

Successful implementation of CRRE practices requires teachers to engage in ongoing critical self-reflection on their own cultural identities and biases, develop deep knowledge of their students' cultural backgrounds, and intentionally design instruction that affirms and draws on students' cultural assets (Allen et al., 2017; Nelson-Barner et al., 2024; Young, 2010). These demands ask teachers to adapt instructional choices in ways that may run counter to long-standing classroom routines. Adoption of CRRE is therefore shaped by more than individual teacher commitment. Teachers are more likely to adopt and sustain CRRE practices when school and district leaders provide sustained professional development and model an organizational commitment to equity-focused instruction (Mathews et al., 2023). In the absence of this institutional support, even teachers who are deeply committed to equity often face barriers to enacting CRRE in ways that are consequential. These challenges with implementation can be especially prominent in STEM courses, which are often perceived as culturally neutral or objective disciplines, despite long-standing patterns of underrepresentation, disengagement, and inequitable outcomes among students from historically marginalized groups (Kolovou, 2023). Given the continued underrepresentation of minoritized populations in STEM majors and careers, the use of CRRE in high school STEM courses is a promising strategy for promoting students' belonging and interest in the field (Estrada et al., 2016).

Research, particularly observational and qualitative case studies, suggest that CRRE approaches have benefits to students, including enhanced achievement, interest, perceived

competence, belonging, and engagement, (see Aronson & Laughter, 2016 and Parkhouse et al., 2019 for reviews; as well as Byrd, 2015; 2016; Cabrera et al., 2014; Dee & Penner, 2017 for quantitative examples). Though quantitative research on CRRE has been limited, it too suggests that CRRE supports motivation, likely via psychological needs for autonomy, competence, and relatedness. For example, Byrd (2016) found in one study using a cross-sectional survey with a racially diverse sample of 6^{th}-12^{th} grade students that CRRE practices were significantly correlated with school interest, feelings of belonging, and perceptions of academic competence.

Integration of CRRE and SDT Perspectives

Key to understanding how SDT and CRRE can be integrated is to note that there are many commonalities across these frameworks (Kumar et al., 2018), including the emphasis on 1) an asset-oriented approach, 2) defining high-quality instructional practices as those that align with students' needs, values, goals, interests, and backgrounds, and 3) promoting student growth and well-being, as well as learning. Both perspectives emphasize that the role of teachers in student motivation is to understand students in order to create opportunities for learning that leverage existing experiences, knowledge, values, and assets. Aligned with SDT's emphasis on the importance of autonomy, CRRE perspectives emphasize the importance of promoting learners' self-initiative free of coercion, self-ownership, and empowerment to act in order to bring about positive outcomes for themselves and social justice for their communities (Kumar et al., 2018; López et al., 2022; Moses, 1997; Raz, 1986). CRRE approaches that attempt to integrate students' cultures into the curriculum support a sense of competence by combating negative stereotypes (e.g., Ladson-Billing, 1995) and by leveraging students' existing interests, values, goals, and knowledge. They also support a sense of belonging by communicating a

strong message that racially and ethnically diverse youth are valued, respected, and cared for in the setting (e.g., Byrd, 2015; Datnow & Cooper, 2000).

In sum, theorical perspectives on CRRE and some limited empirical evidence suggest that it has strong congruence with principles espoused by SDT, likely having benefits for engagement and learning via the satisfaction of basic needs. However, unlike SDT, CRRE is explicit about the cultural and racial experiences of students being key sources of their interests, values, preferences, and goals, and argues that these must be actively integrated into instruction rather than treated as incidental to the learning process. SDT remains race-agnostic, neither theorizing that students' cultural or racial backgrounds shape their perspectives and values nor accounting for how race-neutral instruction may fail to affirm the identities of racially marginalized students. Cultural learning theories directly challenge this assumption, arguing that race, culture, and learning are inherently intertwined and that instruction which ignores this reality cannot fully support all learners. CRRE therefore extends beyond what autonomy support as traditionally defined can offer, particularly for students of color whose cultural and racial identities have historically been absent from or marginalized in curriculum and schooling. Importantly, however, the benefits of CRRE are not limited to racially marginalized students. Evidence suggests that CRRE supports positive outcomes across students of all racial and ethnic backgrounds (Aronson & Laughter, 2016). Moreover, by introducing all students to diverse cultural perspectives and ways of knowing, CRRE prepares students to engage meaningfully and empathetically with people from different backgrounds from their own, which is a competency that is essential for civic participation in an increasingly diverse society.

In this study, we explored these links between SDT and CRRE, focusing particularly on students' perceptions of one key component of CRRE approaches, namely, *cultural engagement*

practices, that is the extent to which teachers incorporate students' culture and home life into discussions and learning activities in the classroom. While CRRE and autonomy support have overlapping goals, they are grounded in distinct theoretical traditions. Therefore, in this study, we aimed to understand whether cultural engagement practices contribute to student outcomes beyond what is explained by autonomy support alone. Modeling them separately enabled empirical tests of whether their effects are additive, overlapping, or interactive, and helped to clarify their respective roles in promoting student engagement.

Interactions between Teacher Practices and with Student Characteristics

Autonomy support seems to be widely adaptive across various student demographics, cultures and contexts (see Parker et al., 2020; Patall & Zambrano, 2019; Reeve, 2009; Washington et al, 2012), but it remains unclear whether cultural engagement practices further enhance its benefits, particularly among U.S. students of color. Cultural engagement practices may moderate the relationship between autonomy support and needs, especially if instructors use autonomy-supportive strategies in a colorblind or Eurocentric manner. Cultural engagement practices should extend autonomy support by affirming students' racial and ethnic identities and tapping into existing experiences and values of diverse students. Thus, diverse urban students' perceptions of receiving cultural engagement practices might not only have direct effects on their basic psychological need satisfaction, but might also enhance the positive relationship between their perceptions of autonomy support with psychological needs. That is, cultural relevance may actually reinforce the functional meaning of autonomy support as respecting and promoting students' volition and self-determination.

Beyond potential interactions between the two approaches, there is some reason to believe that autonomy support and cultural engagement practices might be experienced

differently depending on students' social identities. In this investigation, most participants were U.S. urban students of color from modest income backgrounds, particularly Latinx and Asian, as well as some Black, White, and Middle Eastern students. Given that the urban students of different racial and ethnic backgrounds in this sample are learning in classrooms and communities together, we sought to understand the role of racialized experiences by focusing on students' vulnerability to racial/ethnic stereotypes. We also focused on the role of students' gender identity in these relationships. Students' gender and vulnerability to racial/ethnic stereotypes may be particularly important sources of variation in the relations among teachers' practices and students motivation and engagement in the context of physical science courses, given disparate experiences in science by race and gender, as well as disproportionately low representation of girl students and students of color (particularly, African-American, Latino/a, Native American, Pacific Islander, and Southeast Asian students) in physical science careers (Kang et al., 2023; National Science Board, 2018; Olson & Riordan, 2012; Wang & Degol, 2013).

On one hand, both autonomy support and cultural engagement practices may have equal or greater benefits for groups who have been traditionally subjected to negative stereotypes (e.g., non-White, East, Central, or South Asian boys and girls of all races in the context of science and math) to the extent that both approaches may elevate the particular needs, cultures, interests, values, backgrounds, and identities of underserved and marginalized students (e.g., Aronson & Laughter, 2016; Gay, 2018; Kenny et al., 2010; Parker et al., 2021; Roorda et al., 2011; Solomon et al., 2000; Tucker et al., 2002; Wallace & Sung, 2017). Alternatively, we may see each approach being differentially supportive depending on the nature of how and the extent to which students' identities are marginalized within science. Within the context of science, technology,

engineering and mathematics (STEM), racial/ethnic identity may be the most salient aspect of identity for stigmatization among boy students, given that all areas of STEM have traditionally been and remain male-dominated (U.S. Bureau of Labor Statistics, 2020). For girls, gender may be a more salient aspect of identity than race/ethnicity in STEM stigmatization, particularly within physical science, computer science, engineering, and mathematics. If teacher support is most effective when aligned with students' needs, cultural engagement practices may benefit boys from diverse backgrounds more than girls in STEM courses. Likewise, autonomy supportive practices, which focus on students' personal interests and values, might benefit girls more. Research with racially and ethnically diverse high school students suggests that disparities in perceptions of autonomy support partly explain girls' lower engagement in physical science, suggesting that higher levels of autonomy support may be particularly impactful for girls (Patall et al., 2018a).

The Present Investigation

Autonomy support and cultural engagement practices have great potential for supporting students' motivation, engagement, and learning, particularly in contexts where disengagement is more likely (i.e., COVID-19 pandemic) and within science education, given evidence that STEM teachers use fewer motivationally supportive strategies (e.g., Patall et al., 2023) and ongoing concerns about engaging students in STEM to address disparities in representation and imminent workforce shortages (National Science Board, 2018; 2020). As this data was collected, students transitioned to fully remote learning because of the COVID-19 pandemic. This transition was abrupt and widespread, disrupting not only the logistical structures of schooling but also relational and instructional conditions. This research examined how instructors' motivational and

cultural support influenced students' outcomes during this particularly tumultuous period, where students' need for instructional support may have been particularly heightened.

This research also aimed to contribute to our understanding of psychological mechanisms through which cultural engagement practices support students' outcomes. Moreover, the extent to which there are independent and synergistic relationships between cultural engagement practices and autonomy supportive practices with students' psychological needs and engagement, and variation in these relationships depending on students' marginalized identities within science, is not well understood. Thus, the purpose of the current investigation was to expand our understanding of the relations among racially and ethnically diverse urban high school chemistry and physics students' perceptions of teachers' autonomy supportive and cultural engagement practices and changes in their psychological need satisfaction and engagement over the course of an academic semester. Our research was guided by the following questions.

1. To what extent do racially and ethnically diverse urban high school students' perceptions of their physics or chemistry teachers' autonomy support relate to perceptions of their teachers' cultural engagement practices?
2. To what extent do racially and ethnically diverse urban high school students' perceptions of their physics or chemistry teachers' autonomy support and cultural engagement practices predict changes in their psychological need satisfaction and engagement in the course?
3. To what extent do perceptions of physics and chemistry teachers' autonomy support and cultural engagement practices interact to influence racially and ethnically diverse urban high school students' psychological need satisfaction?

4. To what extent are the relationships between perceptions of physics and chemistry teachers' autonomy support or cultural engagement practices with students' psychological need satisfaction moderated by high school students' gender and racial/ethnic stereotype vulnerability?

To the best of our knowledge, this is the first study to explore these gaps in the research. We hypothesized that autonomy-supportive and cultural engagement practices would be moderately correlated, given a strong alignment of principles and approaches (e.g., Patall et al., 2026) and both would predict an increase in students' science class engagement via an increase in psychological need satisfaction. We also expected to find an interaction between the two forms of teacher supportive practices, such that the presence of one kind of support (i.e., cultural engagement practices) would bolster the positive relationship with psychological needs for the other (i.e., autonomy supportive practices). Finally, we expected to find that the relationships between both forms of support and psychological needs was strongest among students most vulnerable to negative racial or ethnic stereotypes. However, given the relevance of particular aspects of identity for students within the science context, we suspected that cultural engagement practices might have a particularly strong relationship with psychological need satisfaction for boys and autonomy supportive practices might have a particularly strong relationship with psychological need satisfaction for girls.

Methods

Sample and Procedure

This study was part of a broader investigation on classroom engagement that took place in public high schools across a large metropolitan area in California, U.S. between January and May of 2020. Overall, 556 students (48.7% girls, 43.6% boys, 7.7% non-binary or did not report)

in 32 chemistry (54%) and physics (46%) class sections of 10 teachers from five schools participated by completing surveys. Participants ranged between 14 and 18 years of age (Mean age = 15.40 years). Participants were mostly Latino/a or Hispanic; 327 participants were Latino/a or Hispanic (59%); 137 were Asian or Asian American (25%), 35 were European American or White (6%), 34 participants were African American or Black (6%), 5 were Middle Eastern (<1%), 4 were Native American, Pacific Islander, or Native Hawaiian (<1%), and 45 were another race/ethnicity (8%).[1] One-hundred and fifty-six (28.0%) participants were freshman, 171 (30.8%) were sophomores, 162 (29.1%) were juniors, 36 (6.5%) were seniors, and 31 students (5.6%) did not provide this information. Most students in the sample came from modest income backgrounds, with most reporting that they qualified for free or reduced-price lunch (70%) and an additional 17% of participants reporting that they did not wish to share this information or did not know if they qualified. Most students in the sample also reported speaking a language other than English (74%) at home. The average self-reported grade point average (GPA) for the sample was 3.24 on a 4.5 scale (standard deviation = 0.66).

Surveys were administered to students at the start of the semester (Time 1: January/early February 2020) and at the end of the semester (Time 2: May 2020) as part of a larger investigation of an engagement intervention that was delivered following survey completion. The first survey included items to assess students' need satisfaction, engagement, and demographic characteristics. The second survey included items to assess students' perceptions of their teacher's autonomy support and culturally responsive instruction, as well as need satisfaction and engagement, among other variables not related to this analysis. Graduate research assistants administered the Time 1 (T1) web-based surveys to students in their classrooms and emails were

[1] Race/ethnicity categories are not mutually exclusive.

sent to students to complete the Time 2 (T2) web-based survey at home. Students received $5 for returning a consent form and $5 each for completing the first and second survey.

Due to the transition to lockdowns during COVID-19, only two hundred and sixty-six students provided data for both surveys. Students who completed both surveys included slightly more girls (57%), chemistry students (57%), Latino/Hispanic students (62%), Asian (31%) students, students in upper grades (43%), students who qualified for free or reduced-price lunch (77%), students who spoke a language other than English at home (80%), students with just slightly higher grades (Mean GPA = 3.36), and fewer white students (3%).

Student participants were in classes across 10 teachers (M_{Age} = 34.89, SD_{Age} = 11.63) who were mostly European American or White (40%), 10% were African American or Black, 10% were Latino/a or Hispanic, 20% were Asian or Asian American and 20% did not share this information. This sample of teachers were 44.44% male and 55.56% female. In terms of socioeconomic status, 11.11% of teachers identified as working class, 77.78% identified as middle class, and 11.11% identified as upper middle class. On a scale from 1 (strongly disagree) to 5 (strongly agree), teachers on average perceived themselves to be strongly autonomy supportive (M = 4.15, SD = 0.40) and culturally engaging (M = 3.88, SD = 0.54).

Measures

Directions for responding to survey items indicated that students should focus on their current science course experiences. Survey items are listed in the online supplemental materials (OSM).

Psychological need satisfaction was measured with The Balanced Measure of Psychological Needs (Sheldon & Hilpert, 2012). Autonomy, competence, and relatedness satisfaction in class were measured with three items each. Students responded to questions on a

scale from 1 (strongly disagree) to 5 (strongly agree). A six-factor confirmatory factor analysis (CFA) with full information maximum likelihood estimation (FIML), maximum likelihood estimation with robust standard errors (MLR), and the TYPE = COMPLEX option to account for clustering by class was conducted in M*plus* v.8 (Muthén & Muthén, 2017), with items for each type of need satisfaction modeled as loading on its respective factor for either T1 or T2. This model fit the data well (χ^2 = 204.79 [p < .001], CFI/TLI: .98/.98, SRMR: 0.03, RMSEA: 0.04). Loadings for all items on their respective need satisfaction factors were all greater than .62. Next, to reduce complexity and the number of paraments included in a full SEM, composite mean scores were computed for autonomy, relatedness and competence need satisfaction each at T1 and T2 (α ranged from .81 to .96 across timepoints and needs). A two-factor CFA was conducted in which the three-scale means were modeled as loading on need satisfaction at T1 and at T2. Correlated residuals between the same indicator assessed at different time points were included. This model fit the data well (χ^2 = 1.79 [p = .88], CFI/TLI: 1.0/1.0, SRMR: 0.01, RMSEA: 0.00). Loadings for all items on their respective factors were all greater than .65.

Engagement in science class was measured with 8 items from the Engagement versus Disaffection with Learning Student Report (Furrer & Skinner, 2003) to capture behavioral and emotional engagement, 5 items from the Agentic Engagement Scale (AES; 5 items; Jang et al., 2016; Reeve, 2013) to capture agentic engagement, and 4 learning strategies items from Metacognitive Strategies Questionnaire (Wolters, 1994). Items were slightly adapted for consistency with the online learning context at T2 during COVID-19. Students responded to questions using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). An eight-factor CFA fit the data well for each engagement dimension at T1 and T2 (χ^2 = 996.01 [p < .001], CFI/TLI: 0.93/0.92, SRMR: 0.05, RMSEA: 0.04). Standardized loadings were above

.63. Again, to reduce the number of paraments included in a full SEM, composite mean scores were computed for behavioral, emotional, cognitive, and agentic engagement each at T1 and T2 (α ranged from .89 to .93 across timepoints and engagement type). The two-factor CFA using the four scale means on engagement at T1 and engagement at T2 and correlated residuals between the same indicator assessed at different time points fit the data well (χ^2 = 8.82 [p = .89], CFI/TLI: 1.0/1.0, SRMR: 0.02, RMSEA: 0.00). Loadings for all items on their respective factors were all greater than .63.

Student perceptions of their science teachers' *cultural engagement practices* was measured with the 7-item student report cultural engagement subscale from the Student Measure of Culturally Responsive Teaching scale (Dickson et al., 2016). Perceptions of science *teachers' autonomy support* was assessed with the short-version of the Learning Climate Questionnaire (LCQ; 6 items; William & Deci, 1996). All of these items were rated on a 5-point Likert scale ranging from *not at all true* (1) to *extremely true* (5). To first explore the factor structure of the items, we conducted an exploratory factor analysis. Results showed that a 2-factor model fit the data best. Chi-square difference tests showed that a 2-factor model fit significantly better than a 1-factor model, but that a 3-factor model did not fit better than a 2-factor model. Further, the eigenvalues for the two factors exceeded the threshold of 1.0 and factor loadings were all above .76. In addition, a two-factor CFA with both cultural engagement practices and autonomy support items loading on their respective factors fit the data well (χ^2 = 8.75 [p = .02], CFI/TLI: .99/.99, SRMR: 0.04, RMSEA: 0.04). Loadings for all items on their respective factors were all greater than .81. The correlation between the factors was 0.41.

In the T1 survey, we also included a measure of *stereotype vulnerability*. We included three items specifically relevant to the school context from the Rejection Sensitivity (RS) – Race

Questionnaire (Mendoza-Denton et al., 2002) to assess students' vulnerability to stereotypes about their racial or ethnic group. Students rated the extent to which they would be concerned that various negative events described in the items would occur because of their race on a 5-point Likert scale ranging from *very unconcerned* (1) to *very concerned* (5). We conducted a CFA to examine the factor structure of this scale and found that all items loaded well (>.82) on a single factor. The CFA with a single factor and three items was just identified, so fit indices could not be computed. The reliability (Cronbach's α) of all measures used in analyses can be found in Table 1.

Additional covariates of interest were assessed in the T1 survey, including students' gender identity (1 = girls), GPA, grade level, free or reduced-price lunch eligibility status (0 = does not receive free/reduced price lunch, 1 = does receive free/reduced price lunch), and native language (0 = Only English is spoken at home; 1 = Language other than English is spoken at home). Course subject information (0 = Physics; 1 = Chemistry) was collected from teachers at the recruitment stage.

Finally, we conducted a full measurement model, which included T1 and T2 need satisfaction, T1 and T2 engagement, teachers' autonomy supportive practices, and teachers' cultural engagement practices as latent constructs. Results showed that his model fit the data well (χ^2 = 686.49 [p < .001], CFI/TLI: .93/.92, SRMR: 0.06, RMSEA: 0.05). Standardized loadings for all items on their respective factors were all greater than .58.

Measurement Invariance

CFAs for all measures were conducted in M*plus* v.8 (Muthén & Muthén, 2017) focused on testing measurement invariance across time points and between genders. Missing data were handled with full information maximum likelihood estimation (FIML) and maximum likelihood

estimation with robust standard errors (MLR) was used in all analyses. To address within-cluster correlations as a result of students being clustered in classes, we used the TYPE = COMPLEX option within M*plus* to implement robust standard errors using a sandwich estimator. Acceptable model fit was indicated by a comparative fit index (CFI) value of .90 or higher and root mean square error of approximation (RMSEA) and standardized root mean square residual (SRMR) values of .08 or lower (Marsh et al., 2005). Invariance testing involved the comparison of increasingly restrictive configural, metric, and scalar invariance models. For model comparisons, a CFI difference between two models of less than .01 generally indicates a negligible change in overall fit and support for the more parsimonious model (Chen, 2007; Cheung & Rensvold, 2002). We also conducted Satorra-Bentler scaled chi-square difference tests to compare models.

We were able to confirm scalar measurement invariance across time for need satisfaction and engagement. Multigroup CFAs confirmed scalar measurement invariance across gender for engagement at both timepoints, need satisfaction at both timepoints, and perceived teacher practices, including both perceived cultural engagement practices and perceived teacher autonomy support constructs. Further, we confirmed scalar measurement invariance across gender for the full measurement model. Model fit information from these analyses is reported in Table S1 of the OSM.

Analytic Strategy

Once acceptable measurement models and measurement invariance were established, we examined bivariate correlations across variables in preliminary analyses, paying particular attention to the correlation between student perceived cultural engagement practices and teacher autonomy support to address Research Question 1. To address Research Question 2, we then explored the predictive relationships between cultural engagement practices and autonomy

support with student need satisfaction and engagement across the two timepoints in two structural equation models (SEMs) that utilized FIML, MLR, and TYPE = COMPLEX options in *M*plus. Since there were fewer than 50 teachers, we used TYPE=COMPLEX with class as the nesting variable, rather than multilevel modeling, to account for the nested nature of the data (Heck & Thomas, 2020). Further, we included school as a dummy-coded covariate in all models to account for school-level differences in the proposed relationships. We first tested a model (Model 1) in which student perceived cultural engagement practices at Time 2 predicted student need satisfaction at Time 2, and in turn, student engagement at Time 2, controlling for both outcomes at Time 1. The second model (Model 2) added student-perceived teacher autonomy support at Time 2 as a predictor. Both direct paths and indirect paths from perceived teacher practices to engagement via need satisfaction were assessed. Perceived teacher practice variables, need satisfaction, and engagement were all modeled as latent variables. Each model included the same set of covariates predicting need satisfaction and engagement outcomes at Time 2, subject, grade level, gender, GPA, free/reduced price lunch eligibility, and native language, all modeled as manifest variables. These models are depicted in Figure 1 without demographic covariates. The model fit of SEMs was evaluated against the same criteria that had been applied to the CFAs.

Next, we created three new models to explore research questions 3 and 4. In these models, both perceived teacher practices at Time 2 were used to predict students' need satisfaction at Time 2, controlling for the outcome at Time 1 and the same set of covariates as prior models. However, also included in these models were interactions between perceived teacher practice variables and students' stereotype vulnerability or gender. A latent moderated structural equation approach (Klein & Moosbrugger, 2000) was used by adding the XWITH

statement option of the MODEL command in *M*Plus to specify an interaction between either the two latent variables or between an observed (e.g., gender) and latent variable (Muthén & Muthén, 2009). Interactions between the two perceived practices (Model 3), between practices and stereotype vulnerability (Model 4), and between practices and gender (Model 5) were included in three separate models (depicted in Figure 2 without demographic covariates). This approach does not allow for computation of fit indices (Maslowsky et al., 2015). We computed simple effects to better understand significant interactions.

Transparency and Openness

This study follows the Journal Article Reporting Standards (Appelbaum et al., 2018). We report inclusion criteria, data collection procedures, and all study measures. Due to requirements of collaborating schools, the materials, data, and analysis code for this study are only available by emailing the corresponding author. This study is part of a larger project that was preregistered (https://osf.io/pr3j5). The analyses reported in this paper were not preregistered.

Results

Preliminary Analyses

Descriptive statistics and bivariate correlations are shown in Table 1. Correlations among cultural engagement practices, autonomy support, need satisfaction, and engagement were in the expected directions and all statistically significant. Notably, the bivariate correlation between cultural engagement practices and autonomy support was .39, suggesting that the practices co-occur. Moreover, correlations between autonomy support with need satisfaction and engagement were stronger than correlations between cultural engagement practices with these outcomes. Several statistically significant correlations also emerged between key variables and

demographic variables (e.g., grade level, gender, etc.). Being a girl[2] was correlated with lower need satisfaction at Time 1 (T1) and Time 2 (T2), as was being enrolled in a chemistry class (compared to physics) at T1. Eligibility for free or reduced-price lunch was also associated with lower engagement (T1). Statistically significant positive correlations between GPA and engagement (T1 and T2), need satisfaction (T1), and perceived autonomy support (T2) emerged. In support of the use of TYPE = COMPLEX in models to account for clustering, ICCs for the latent variables ranged from 6% to 39% of the variation being attributed to the classroom (see Table 1), with smaller ICCs for outcomes at Time 2.

Relationships Among Perceived Teacher Practice, Need Satisfaction, and Engagement

Model 1 fit the data well (χ_2 = 723.18, *df* = 364, CFI = .90, RMSEA = .05, SRMR = .08, see Table 2). Structural equation models indicated that students' perceptions of cultural engagement practices predicted a statistically significant increase in students' psychological need satisfaction (β = .21, p = .001) relative to the beginning of the semester, and need satisfaction predicted a statistically significant increase in engagement (β = .96, p < .001). The indirect effect of perceived cultural engagement practices on engagement via need satisfaction was also positive and statistically significant (β = .20, p = .002). Need satisfaction was also lower among girls than boys (β = -.16, p < .001).

Model 2 fit the data well (χ_2 = 1012.05, *df* = 554, CFI = .90, RMSEA = .05, SRMR = .08, see Table 2). Structural equation models indicated that students' perceptions of cultural engagement practices no longer predicted a statistically significant change in students' psychological need satisfaction (β = .10, p =.13) with perceived teacher autonomy support

[2] Five students indicated "other/non-binary" as their gender. Due to the small sample size of this group, relationships between "other/non-binary" genders and focal variables could not be analyzed with the current data. Gender information was treated as missing in analyses for "other/non-binary" students.

included in the model, which predicted a statistically significant change in students' psychological need satisfaction ($\beta = .38$, $p < .001$). Students' need satisfaction continued to predict a statistically significant increase in engagement ($\beta = .87$, $p < .001$). The indirect effect of perceived teacher autonomy support on engagement via need satisfaction was also positive and statistically significant ($\beta = .33$, $p < .001$). However, the indirect effect for perceived cultural engagement practices was not statistically significant ($\beta = .09$, $p = .15$). Again, need satisfaction was also lower among girls than boys ($\beta = -.15$, $p = .001$).

Interactions among Perceived Teacher Practices, Stereotype Vulnerability, and Gender in Predicting Need Satisfaction

Next, we explored a series of models to examine whether perceived teacher autonomy support and cultural engagement practices interacted to predict changes in students' experience of psychological need satisfaction, as well as whether the relationships between the perceived teacher practice variables and need satisfaction varied depending on students' stereotype vulnerability or gender. Results suggested that the latent interaction between the two perceived teacher practice variables was not statistically significant (see Table S2 of OSM). Likewise, the latent interactions between stereotype vulnerability with perceived teacher autonomy support and culturally responsive instruction were not statistically significant (see Table S2 of OSM).

However, gender statistically significantly interacted with perceived cultural engagement practices to predict changes in need satisfaction ($B = -0.14$, $SE = 0.05$, $p = .008$; see Table S2 of OSM). Probing this interaction with simple slopes revealed that perceived cultural engagement practices predicted a statistically significant increase in need satisfaction for boys ($b = 0.24$, $SE = 0.05$, $p < .001$), but not for girls ($b = 0.01$, $SE = 0.07$, $p = .84$). The interaction between gender and perceived autonomy support was not statistically significant at the traditional $p < .05$ level,

but it was marginally significant at $p = .07$ ($B = 0.09$, SE $= 0.05$, $p < .07$; see Table S2 of OSM). Given that this interaction was only marginally significant, we did not probe it further, but we note that the positive direction of the non-significant interaction coefficient favoring girls.

Discussion

The present investigation examined the extent to which culturally and racially diverse urban high school chemistry and physics students' perceptions of their teachers' cultural engagement practices and autonomy support predicted their need satisfaction and engagement in class over the course of a semester during the onset of the COVID-19 pandemic. We also examined whether the teacher practices interacted to predict need satisfaction and whether the relationship between practices and need satisfaction varied depending on students' stereotype vulnerability and gender.

Consistency of Findings with Hypotheses Based on Theory

Many findings from this study were in line with our predictions and consistent with culturally responsive (e.g., Gay, 2018) and self-determination theories (e.g., Ryan & Deci, 2017) that we drew on to guide hypotheses. As we predicted, we found that urban high school students' perceptions of their science teachers' cultural engagement practices predicted an increase in their psychological need satisfaction, compared to earlier in the semester. Moreover, this increase in need satisfaction, in turn, predicted an increase in engagement over the course of the semester. Culturally relevant and responsive education (CRRE) frameworks emphasize the importance of promoting the cultures and contributions of the learners' communities, their connection with others, and their empowerment to act on one's own behalf and that of one's community in order to propel learning and growth (Gay, 2018; Kumar et al., 2018; Ladson-Billing, 1995; López et al., 2022; Moses, 1997; Raz, 1986). Given these emphases, the importance of experiences of

autonomy, competence, and relatedness need satisfaction seems intrinsic to the approach. Along these lines, this study provides initial evidence that psychological need satisfaction is a mechanism by which culturally relevant approaches may yield benefits for students' engagement and learning outcomes. As this data was collected, students transitioned to remote learning due to the COVID-19 pandemic. Against this backdrop, our results highlight that even during this tumultuous period, many students perceived that their instructors were culturally supportive. This suggests that teachers were able to maintain and communicate culturally responsive and relevant practices even as they navigated an unprecedented shift to remote instruction, which speaks to both the adaptability of skilled educators and the applicability of CRRE practices across educational contexts. Future research should continue to examine how culturally responsive teaching practices function across varied and challenging learning contexts.

Not surprisingly, results were also consistent with theory and prior research from a self-determination theory perspective suggesting that students' adaptive functioning follows teachers' support for psychological needs (e.g., Jang et al., 2016). Consistent with prior studies on student engagement (e.g., Patall et al., 2018b), results of this investigation indicated that high school students' perceptions of their science teachers' autonomy support predicted an increase in their need satisfaction, and in turn, their engagement across the semester. This finding shows that even during a tumultuous transition to online learning during the onset of the COVID-19 pandemic, students still experienced benefits from autonomy supportive instruction, showing that autonomy supportive instruction has potential to be successfully implemented even in challenging educational contexts. Moreover, consistent with our hypotheses was the finding that teachers' cultural engagement practices and autonomy support were moderately correlated, a finding that

supports our claim that there is strong congruence in principles espoused by CRRE and SDT (e.g., Kumar et al., 2018; Patall et al., 2026).

There were also findings somewhat counter to our predictions. Given that CRRE is explicit about the cultural and racial experiences of students being key sources of their interests, values, and goals to be leveraged in the curriculum, we expected that cultural engagement practices would have benefits beyond autonomy support among this sample of largely students of color. Prior evidence shows support for this relationship, where racially minoritized college students' perceptions of their instructor's promotion of cultural competence and cultural socialization were associated with their need satisfaction and in turn, their engagement in class over and above their perceptions of autonomy support (Vite et al., 2025). However, results of this investigation indicated that once perceived teacher autonomy support was included in the model, student perceptions of cultural engagement practices no longer predicted a change in students' need satisfaction above and beyond the effect of autonomy support without considering variation in students' gender, which we discuss more next. We presume this finding is likely due to the (expected) overlap in how students perceive these constructs. Our factor analytic results reinforce this interpretation showing that the empirical boundaries between autonomy support and culturally relevant and responsive practices are less distinct than current theoretical accounts suggest. This pattern raises theoretical questions with implications for both frameworks. When teachers honor students' lived experiences, draw on their cultural and linguistic resources, and treat their identities as assets in the learning process, students may experience these actions as deeply autonomy-supportive. Instructors' autonomy support, as students actually encounter it, may be inseparable from the relational and sociocultural conditions that make classrooms feel responsive to students' backgrounds. Future work might therefore approach SDT and CRRE as

mutually shaping perspectives, examining where they converge and diverge empirically. Rather than treating CRRE and autonomy support as competing or redundant frameworks, future work should explore how they can be conceptualized as complementary.

Nonetheless, in line with prior research, these results underscore the generalized importance of teachers' autonomy supportive practices to the adaptive functioning and engagement in the classroom across students of various backgrounds (e.g., Patall & Zambrano, 2019). This finding represents an important contribution to the literature, particularly given that limited prior research has tested these patterns of relationships with racially and ethnically minoritized U.S. samples. Much of the existing work on autonomy support and student engagement has been conducted with predominantly White or homogenous samples, limiting the generalizability of autonomy-supportive practices across diverse student groups. While SDT scholars claim that support for basic psychological needs is universally related to positive outcomes, we encourage researchers to continue to corroborate this claim with evidence from demographically and contextually diverse samples.

Gender Moderates the Cultural Engagement-Need Satisfaction Relation in Science

We examined whether the teacher practices interacted to predict need satisfaction and whether the relationship between practices and need satisfaction varied depending on students' stereotype vulnerability and gender. In contrast to our predictions, perceived teacher practices did not interact, nor did we find that the relationships between perceptions of teachers' supportive practices and psychological needs were strongest among students most vulnerable to negative racial or ethnic stereotypes. We think these findings point to how essential teachers' autonomy supportive practices are for class engagement across students of various backgrounds.

However, consistent with our predictions, we did find that the relationship between cultural engagement and need satisfaction varied by gender. Specifically, we found a statistically significant positive relationship between cultural engagement practices and psychological need satisfaction for only boys and not girls. These findings underscore that the effects of teachers' practices are partly dependent on the identity of students within the specific context. In this case, for boys, ethnic or racial identity may be particularly salient, as most areas of STEM are male-dominated (U.S. Bureau of Labor Statistics, 2020) and people of color remain underrepresented (Kang et al., 2023; National Science Board, 2018; Olson & Riordan, 2012; Wang & Degol, 2013). Cultural engagement practices may enhance need satisfaction above and beyond autonomy support for boys, in particular, by serving to counter the traditional underrepresentation of some racial and ethnic groups' perspectives in science curriculum. Essentially, cultural engagement strategies provide value-added support for the cultural aspects of boys' interests, values, and goals that may be saliently neglected across science contexts, while their identity as boys is not.

In contrast, the positive relationship between autonomy supportive practices and psychological need satisfaction was positive and significant for both boys and girls. We note that although the positive interaction was not statistically significant at the conventional $p < .05$ level, it was marginally significant (at $p < .07$), suggesting that we might have detected a stronger relationship between perceived autonomy support and need satisfaction for girls compared to boys with greater statistical power. Taken together, this pattern of findings related to gender interactions also points to the likelihood that for girls, race and ethnicity may not be the most salient factor for stigmatization in STEM, given pervasive stereotypes associating math-intensive, physical sciences with innate talent that men possess more so than women (e.g., Leslie

et al., 2015; Nosek et al., 2009; Tiedemann, 2002). Consistent with gender stereotypes in science, research demonstrates that racially and ethnically diverse girls routinely report lower levels of perceived competence, interest, and need satisfaction in STEM during adolescence compared to their boy counterparts (e.g., Patall et al., 2018a; Wang & Degol, 2013, 2017), and experience differential treatment by teachers, including less autonomy support (e.g., Patall et al., 2018a). Given the male-dominated nature of science, it may align with fewer aspects of girls' identities, interests, goals, and values. Autonomy support seems to fill a critical gap in girls' experience in science by helping to align science experiences better with personal interests, values, and goals, just as it does for boys. However, the importance of aligning girls' experiences in science with their cultural backgrounds appears to be secondary to supporting their personal autonomy in the context of strong racially-generalized, gender stereotypes in science. That explanation aside, it is also possible, though not clearly established with the current data, that the strong relationship between autonomy support and needs may also potentially crowd out any additional benefits of cultural engagement practices for girls in particular. Alternatively, it is possible that socialization processes that emphasize agreeableness among women (e.g., Wood & Eagly, 2002) may encourage girls of color, who face multiple negative stereotypes in STEM, more so than boys to adapt to racially white norms in science classroom spaces (e.g., Johnson et al., 2022). This socialization may render cultural engagement practices to be a less powerful form of support compared to autonomy support among girls, though evidence in the prior literature supporting this explanation is limited.

Limitations

While this study provides meaningful insight on the combined contribution of autonomy supportive and culturally relevant instruction on students' engagement, several key limitations

constrain the interpretation of results. First, we did not explore relationships separately for different racial groups and instead focused on whether students' racial or ethnic stereotype vulnerability explained any variation in the effects. We believe this approach is a strength, as stereotype vulnerability is a useful explanatory variable for why differences could have emerged. From a QuantCrit perspective, controlling for race in analyses is not always a meaningful representation of the racism implicated in the measurement of race (Fong & Irizarry, 2025). By examining how students' stereotype vulnerability may have affected the relationships of interest, we more acutely accounted for the impact of systems of oppression on students' experiences in class. Nonetheless, we recommend that future research examine the relationships observed in the current study with large student samples of specific racial and ethnic groups, examined separately, with more attention given to race- and ethnicity-specific cultural variables and teacher characteristics that might explain the pattern of relationships. Further, qualitative research would enhance our understanding of how racially, ethnically, and culturally diverse students interpret autonomy support in the context of their cultural identities.

Additionally, this study relied on student-reported data which may be subject to response bias and shared-method variance. An important step for future research is to use observational data or teacher reports. In addition, we recommend that future research explore the focal relationships using different time frames and different contexts. We believe the context for this study, urban high school physical science classrooms, meaningfully influenced results, making it important to explore the relationships among teacher practices, need satisfaction, and engagement in different subjects, at different developmental stages, and in different school levels and settings.

Further, the short longitudinal design, with two timepoints and teacher practices measured only at Time 2, limits the conclusions about change that can be drawn from our analyses. Because our models do not control for students' perceptions of their instructors' autonomy support or CRRE at Time 1, we cannot determine whether teaching practices predicted changes in need satisfaction or engagement over time. Accordingly, the effects from teaching practices to student outcomes should be interpreted as cross-sectional rather than longitudinal in nature. Future research would benefit from designs that include teacher practice measures at multiple timepoints, enabling stronger causal inference about the directionality of relationships examined.

Finally, the relatively small sample size both at Time 1 and Time 2 limits the statistical power of our analyses, particularly our results from the structural equation models. The reduction in sample size across time points, primarily attributed to disruptions in instruction associated with the onset of COVID-19, also raises concerns about attrition bias. Students who did not complete measures at Time 2 may differ systematically from those who did on key variables, which could threaten the representativeness of the Time 2 sample. The decline in ICCs from Time 1 to Time 2 for students' engagement and need satisfaction may be evidence of such attrition bias, indicating that classroom level variance decreased over time (see Table 1). Future studies should employ larger, more diverse samples and strategies to minimize attrition. Replication of these findings in larger samples would strengthen confidence in the stability and generalizability of the effects reported.

Implications and Future Directions

The findings from this investigation suggest that teacher practices that support student autonomy and cultural relevance are critically important to the engagement of racially and

culturally diverse high school students. This investigation makes an important contribution by showing that need satisfaction is a critical mechanism by which cultural engagement practices support student outcomes and is the first to simultaneously explore the relationships between both autonomy support and cultural engagement practices with students' need satisfaction and engagement and over time, particularly among urban U.S. students of color from modest income backgrounds. In line with prior evidence, this study points to the benefits of teachers' autonomy support for diverse, urban U.S. students' need satisfaction and engagement, for whom evidence on these relations has been limited. This study also highlights complex interactions with students' gender and the importance of considering multiple student identities within a science context. In line with prior evidence (e.g., Aronson & Laughter, 2016; Patall & Zambrano, 2019; Reeve & Cheon, 2021), this evidence continues to highlight the promise of interventions that target support for students' psychological needs and cultural relevance in order to engage diverse students in science.

Some research indicates that instructor resistance to autonomy-supportive and culturally responsive and relevant practices is often rooted in perceived feasibility barriers, including the belief that such strategies demand more time and resources than everyday teaching contexts allow (Reeve et al., 2014; Young, 2010). We argue, however, that the unique context of this research challenges that perception. Students and instructors in this study were simultaneously adapting to profound disruptions in their everyday lives and schooling experiences during the onset of the COVID-19 pandemic. Although many teachers across the U.S. experienced significant burnout, stress, and uncertainty during this period, students in this sample still perceived their use of autonomy-supportive and culturally responsive instruction at levels that were meaningfully associated with need satisfaction and engagement (Pressley, 2021). This

finding shows that rather than being an added burden, these strategies are adaptable and may even be most consequential when learning conditions are most challenging. However, while the pandemic context highlights the importance of motivationally and culturally supportive teaching under adverse conditions, it also necessitates caution in generalizing the results to more typical instructional settings. We recommend that future research continues to examine these relationships in fully in-person instructional settings.

We hope that this investigation will provide a basis for replication and extension in future research. While findings from this study did not suggest that CRRE was associated with changes in students' need satisfaction above and beyond the effect of autonomy support consistently across gender, we believe that it is important for future empirical research to focus on understanding how SDT and CRRE approaches can be meaningfully integrated and used to powerfully explain, predict, and support students' academic success, particularly that of racially and ethnically minoritized students (e.g., DeCuir-Gunby & Schutz, 2014; 2024). One important approach is to test these relationships longitudinally, particularly to discern whether CRRE predicts changes in students' need satisfaction, and engagement over time. Further, while there is theoretical overlap between CRRE and autonomy support, more research is needed to understand the empirical connections between these teaching practices. It remains unclear, for instance, whether CRRE operates partly through its capacity to foster autonomy support, such that culturally responsive practices create the relational and motivational conditions under which autonomy-supportive instruction becomes possible, or whether the two practices are better understood as co-occurring but conceptually distinct dimensions of high-quality teaching. One methodological approach for future research is to use a cross-lagged panel model to determine the direction of effects between instructors' use of CRRE and autonomy support. Such a design,

with teacher practice measures collected at multiple timepoints, would allow researchers to test whether early levels of one practice predict later levels of the other while controlling for their prior association, providing clearer evidence about whether and how these constructs influence one another over time. Qualitative and observational approaches may also complement this work by illuminating the mechanisms through which CRRE and autonomy support intersect in classroom practice, moving beyond self-report and perception measures toward a richer understanding of how these teaching behaviors manifest and interact in real instructional contexts. Beyond cultural engagement practices, we recommend that future research explore the extent to which other dimensions of culturally relevant and responsive education (i.e., support for critical consciousness skills) are related to and can be integrated with autonomy support to support students' outcomes. Eventually, we hope that future research can focus on the development and testing of interventions that train teachers on instructional strategies integrate SDT and CRRE approaches to fully support the motivational needs of racially and ethnically diverse students.

Conclusion

This investigation contributes to an important emerging research base designed to understand the role of teachers' motivating and culturally relevant instructional practices in the engagement of culturally and racially diverse U.S. high school science students. Results highlight the importance of both teachers' support for autonomy and cultural relevance in urban adolescents' need satisfaction and science class engagement, as well as heterogeneity depending on students' gender identities. We encourage researchers and educators to continue to explore ways to effectively integrate and leverage these practices in order to create positive motivational environments that allow all students to thrive.

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Table 1

Descriptive Statistics and Observed Bivariate Correlations

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Grade level													
2. Subject	.16**												
3. Gender	-.04	.05											
4. FRL	-.05	.25**	-.07										
5. Native Lang.	-.06	.11*	.10*	.33**									
6. GPA	.14**	-.17**	.07	-.11*	-.06								
7. SV	-.12	-.02	.11*	.03	.02	-.07							
8. Engage T1	.07	-.05	.05	-.16**	-.04	.26**	-.08						
9. Engage T2	-.03	-.05	-.05	-.09	.04	.21**	-.02	.66**					
10. Need Sat T1	.07	-.09*	-.11*	-.09	-.07	.27**	-.11	.73**	.46**				
11. Need Sat T2	-.03	-.09	-.19**	-.08	.07	.10	-.03	.54**	.74**	.61**			
12. Cult Eng T2	.04	.04	-.01	.01	.06	.09	.004	.24**	.32**	.20**	.32**		
13. Aut Support T2	-.07	-.004	-.03	.02	.05	.15*	-.005	.48**	.69**	.40**	.60**	.39**	
M	2.15	0.54	0.53	0.90	0.81	3.24	2.31	3.77	3.69	3.62	3.47	2.84	3.85
SD	0.93	0.50	0.50	0.31	0.39	0.66	1.71	0.66	0.74	0.75	0.90	1.00	0.90
N	525	556	513	432	511	494	525	527	274	528	276	268	269
Cronbach's α							.89	.79	.84	.70	.83	.94	.94
ICC							.09	.21	.06	.39	.13	.22	.15

Notes. $^{*}p < .05$. $^{**}p < .01$. Subject = course subject (1 = chemistry). Gender = student gender (1 = girl). Native lang. = native language (1 = language other than English). FRL = free or reduced-price lunch (1 = eligible). GPA = grade point average. SV = stereotype vulnerability ((All items were rated on a 5-point scale ranging from 1 (very unconcerned) to 5 (very concerned)). T1 = Time 1. T2 = Time 2. Engage. = Engagement (All items were rated on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree)). Need Sat = Psychological need satisfaction (All items were rated on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree)). Cult Eng = Perceived cultural engagement practices (All items were rated on a 5-point scale ranging from 1 (not at all true) to 5 (extremely true)). Aut Support = Perceived teacher autonomy support (All items were rated on a 5-point scale ranging from 1 (not at all true) to 5 (extremely true)). M = Mean. SD = Standard deviation. N = Number of participants. ICC = Intraclass correlation coefficient.

Table 2

Estimates (and Standard Errors) for Structural Equation Model 1 and Model 2

	Model 1				Model 2			
Predictor	**Need Sat T2**		**Engage T2**		**Need Sat T2**		**Engage T2**	
	Unstand	**Stand**	**Unstand**	**Stand**	**Unstand**	**Stand**	**Unstand**	**Stand**
Cult Eng T2	0.16*** (0.04)	0.21** (0.06)	0.01 (0.04)	0.01 (0.06)	0.08 (0.05)	0.10 (0.07)	-0.01 (0.04)	-0.01 (0.06)
Aut Support T2	--	--	--	--	0.36*** (0.07)	0.38*** (0.07)	0.14ǂ (0.08)	0.16ǂ (0.08)
Need Sat T1	0.75*** (0.10)	0.65*** (0.04)	--	--	0.54*** (0.09)	0.47*** (0.06)	--	--
Need Sat T2	--	--	0.92*** (0.11)	0.96*** (0.06)	--	--	0.87*** (0.12)	0.87*** (0.08)
Engage T1	--	--	0.06 (0.07)	0.05 (0.06)	--	--	0.04 (0.06)	0.04 (0.05)
School 1	-0.31* (0.09)	-0.20** (.06)	0.02 (0.12)	0.01 (0.08)	-0.31* (0.12)	-0.20* (0.08)	-0.02 (0.10)	-0.01 (0.07)
School 2	-0.13 (0.12)	-0.07 (.07)	-0.12 (0.11)	-0.06 (0.06)	-0.12 (0.15)	-0.06 (0.08)	-0.12 (0.09)	-0.07 (0..05)
School 3	-0.01 (0.15)	-0.01 (.05)	-0.36** (0.14)	-0.13* (0.06)	-0.13 (0.18)	0.04 (0.06)	-0.30** (0.11)	-0.10* (0.05)
School 4	-0.27 (0.20)	-0.09 (.07)	-0.10 (0.17)	-0.03 (0.06)	-0.21 (0.20)	-0.07 (0.07)	-0.10 (0.15)	-0.03 (0.05)
Grade level	-0.07 (0.05)	-0.08 (0.06)	-0.05 (0.04)	-0.06 (0.05)	-0.02 (0.05)	-0.03 (0.06)	-0.04 (0.03)	-0.05 (0.04)
Subject	0.03 (0.10)	0.02 (0.07)	0.00 (0.07)	0.00 (0.05)	0.02 (0.10)	0.01 (0.07)	0.00 (0.06)	0.00 (0.04)
Gender	-0.25** (0.08)	-0.16** (0.05)	0.11ǂ (0.06)	0.07ǂ (0.04)	-0.24** (0.08)	-0.15** (0.04)	0.09ǂ (0.06)	0.06ǂ (0.04)
GPA	0.07 (0.08)	0.06 (0.07)	0.01 (0.06)	0.01 (0.06)	0.05 (0.08)	0.04 (0.07)	0.02 (0.06)	0.01 (0.05)
FRL	-0.18 (0.17)	-0.07 (0.07)	0.03 (0.10)	0.01 (0.04)	-0.22 (0.16)	-0.09 (0.07)	0.00 (0.09)	0.00 (0.04)
Nat. Lang.	0.19 (0.13)	0.09 (0.06)	-0.11ǂ (0.06)	-0.05ǂ (0.03)	0.22* (0.10)	0.11* (0.05)	-0.08 (0.06)	-0.04 (0.03)
Covariances	**Unstand**		**Stand**		**Unstand**		**Stand**	
Cult Eng T2– Aut Support T2	--		--		0.36*** (0.07)		0.42*** (0.06)	
Need Sat T1 – Cult Eng T2	0.17** (0.06)		0.23** (0.08)		0.16** (0.06)		0.24** (0.08)	
Engage T1 – Cult Eng T2	0.19** (0.07)		0.29** (0.09)		0.19** (0.07)		0.29*** (0.09)	
Need Sat T1 – Aut Support T2	--		--		0.34*** (0.07)		0.60*** (0.08)	
Engage T1 – Aut Support T2	--		--		0.30*** (0.05)		0.57*** (0.07)	
Need Sat T1 – Engage T1	0.44*** (0.05)		1.02*** (0.02)		0.44*** (0.05)		1.03*** (0.03)	
Indirect Effects								
Cult Eng T2 □ Need Sat T2 □Engage T2	0.15** (0.05) 95% CI [0.05/0.24]		0.20** (0.07) 95% CI [0.08/0.33]		0.06 (0.04) 95% CI [-0.05/0.15]		0.09 (0.06) 95% CI [-0.03/0.20]	
Aut Support T2 □ Need Sat T2 □Engage T2	--		--		0.30*** (0.07) 95% CI [0.17/0.43]		0.33*** (0.08) 95% CI [0.18/0.48]	
Total Effects								
Cult Eng T2 □Engage T2	0.15*** (0.04) 95% CI [0.07/0.23]		0.21*** (0.06) 95% CI [0.10/0.33]		0.05 (0.04) 95% CI [-0.02/0.13]		0.07 (0.05) 95% CI [-0.03/0.18]	
Aut Support T2 □Engage T2	--		--		0.45*** (0.07); 95% CI [0.31/0.58]		0.49*** (0.05) 95% CI [0.38/0.59]	
Model Fit	χ^2 (df) = 723.18 (364), p = < .001 CFI = .90, TLI = .89 RMSEA = .050 [95% CI .045/.056] SRMR = .080				χ^2 (df) = 1012.05 (554), p = < .001 CFI = .90, TLI = .89 RMSEA = .046 [95% CI .042/.051] SRMR = .077			

Notes. ǂp < .10. *p < .05. **p < .01. ***p < .001. T1 = Time 1. T2 = Time 2. Unstand = Unstandardized coefficients (and standard errors). Stand = Standardized coefficients (and standard errors). Need Sat = Psychological need satisfaction. Engage. = Engagement. Cult Eng = Perceived cultural engagement practices. Aut

Support = Perceived teacher autonomy support. School 1-4 = Dummy coded school covariate (School 5 is reference group); Subject = course subject (1 = chemistry). Gender = student gender (1 = girl). GPA = grade point average. FRL = free or reduced-price lunch (1 = eligible). Native lang. = native language (1 = language other than English). Standard errors in parentheses. Measurement model for latent variables not displayed. 95% CI = 95% Confidence Interval.

Figure 1
Illustration of Model 1 and Model 2

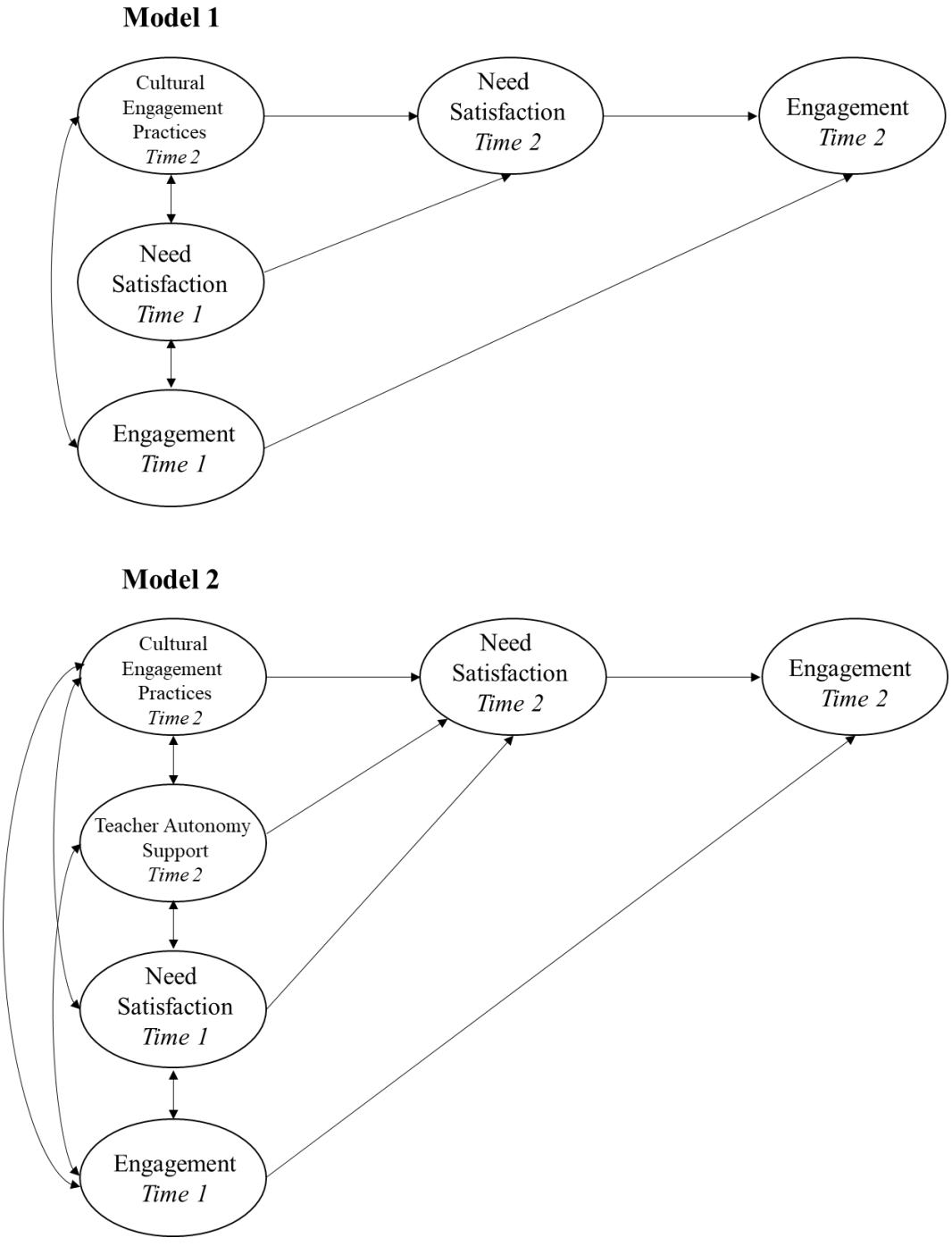


Figure 2

Illustration of Model 3, Model 4, and Model 5

