Daily autonomy, relatedness, and classroom engagement among Latino and White high school science students

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Abstract

According to self-determination theory (SDT), students have basic psychological needs for autonomy, competence and relatedness that must be satisfied in order for them to experience optimal functioning in the classroom. While SDT asserts these needs are universal, cross-cultural studies have indicated that there may be some variation in the associations of these needs with motivational outcomes. In this study, we surveyed white ($n=70$) and Latino ($n=87$) American high school students over a six-week period to examine the extent to which students' daily perceptions of autonomy and relatedness need satisfaction independently and interactively predicted their daily science engagement, and whether these relationships differed for white and Latino students. Multilevel modeling analyses suggest that autonomy and relatedness are uniquely and interactively predictive of science engagement for white and Latino students. However, cultural variation emerged as well: daily autonomy had a stronger relationship with engagement for Latino students, while daily relatedness had a stronger relationship with engagement for white students. Results suggest the importance of considering students' cultural backgrounds when examining the unique and interactive relationships between psychological need satisfaction and engagement in science.

Keywords Science engagement · Motivation · Psychological need satisfaction · Race/ethnicity · High school

Introduction

The decline of student engagement in adolescence (Martin, 2009), particularly in STEM subjects (i.e., science, technology, engineering, and mathematics), has been well reported in previous research (Maltese & Tai, 2011). Self Determination Theory (SDT) is a useful organizing framework to understand and support student engagement in science. Specifically, SDT asserts that students have basic psychological needs for autonomy, relatedness, and competence that must be satisfied in order for them to be motivated and engaged in the classroom (Ryan & Deci, 2020). However, there continues to be debate regarding the universality of

the psychological needs of autonomy and relatedness (e.g., Iyengar & Lepper, 1999). Some scholars argue that the significance of the needs on student engagement may differ for students from collectivist vs. individualist cultures due to differing norms and values around the self and group (Markus & Kitayama, 1991). To better understand the role of need satisfaction (i.e., the satisfaction of autonomy, competence, and relatedness needs) on science engagement, as well as the role of culture in the relationship between students' needs and engagement in science class, we explored the extent to which daily autonomy and relatedness need satisfaction independently and interactively predicted daily science engagement for U.S. high school students from Latino and white American cultures respectively.

Student psychological needs and engagement

SDT states that individuals have three fundamental psychological needs of autonomy, relatedness, and competence that universally underlie motivation and engagement (e.g., Ryan &

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Deci, 2017). That is, in order for individuals to be intrinsically motivated and engage, they must feel a sense of autonomy (i.e., feel as if one's actions are volitional and free of external control), relatedness (i.e., a sense of connection with others), and competence (i.e., effective and a sense of accomplishment in one's pursuits). When students' basic psychological needs are met in the classroom, they feel internally motivated to participate and create meaningful, productive experiences in class (e.g., Cheon et al., 2012; Ryan & Deci, 2017). Indeed, research has routinely found that students' need satisfaction promotes active participation and engagement, while the thwarting of these needs leads to various forms of disengagement in STEM classes (e.g., Jang et al., 2016).

Student engagement refers to students' active involvement in a learning activity and is considered a multifaceted construct made up of distinct components: *emotional* (i.e., presence of task-facilitating vs. task-withdrawing emotions during a learning activity), *behavioral* (i.e., visible, on-task attention, concentration, effort, and persistence), *cognitive* (i.e., use of self-regulatory strategies, personalized learning strategies, and pursuit of deep, conceptual understanding of material), and *agentic* (i.e., active participation and contribution in shaping the flow of learning activities; Reeve, 2012). Student engagement has been shown to mediate the relationship between student motivation and achievement outcomes (e.g., Reeve, 2012; Reeve & Tseng, 2011). For example, León et al. (2015) found student autonomy predicted autonomous motivation, which in turn predicted engagement (e.g., effort, deep-processing, etc.), and ultimately math achievement for high school students.

Psychological needs: a universalist vs. social-constructivist debate

While SDT posits that the psychological needs of autonomy, relatedness, and competence are universal regardless of culture, social constructivist theorists argue that psychological needs are not innate but rather constructed by their cultural context (e.g., Burr, 2003; Iyengar & Lepper, 1999). In particular, the need for autonomy and relatedness may differ as a function of cultural differences regarding self and group-related values between collectivist vs. individualist cultures (Triandis, 1995). That is, individuals from *collectivist* cultures generally prioritize group obligations and group goals over the self, and other people play an important role in how one defines the self (Markus & Kitayama, 1991; Singelis, 1994). On the other hand, individuals from *individualist* cultures generally prioritize independence and personal goals over the group, and while relationships are still valued, other people do not play a central role in how one defines the self (Markus & Kitayama, 1991). The

social constructivist framework asserts that the impact of need satisfaction on students' functioning is influenced by the cultural importance placed on each need (e.g., Iyengar & Devoe, 2003). Thus, the satisfaction of students' need for relatedness may be more important for students with cultural heritage that prioritizes the group, while the satisfaction of students' need for autonomy may be more important for students with cultural heritage that prioritizes the self.

SDT, on the other hand, asserts that autonomy, relatedness, and competence are essential "psychological nutrients" that students require to experience well-being and optimal functioning in the classroom regardless of cultural background (Ryan & Deci, 2000). According to this view, while the expression of these needs may be shaped by cultural practices, their underlying importance remains constant (e.g., Taylor & Lonsdale, 2010). Research has provided support for the universal importance of all three needs across different cultures. A growing body of studies conducted in countries with collectivist cultures (e.g., South Korea, China) have found the three needs relate to student outcomes like motivation, achievement, and vitality (e.g., Jang et al., 2009; Vansteenkiste et al., 2006). In a study on young adults across Belgium, China, Peru, and the U.S., researchers found the satisfaction of each of the three needs uniquely predicted well-being, while frustration of each need uniquely predicted ill-being (Chen et al., 2015). This study suggested the relationships between psychological needs and well- or ill-being did not vary by cultural or individual differences in the value of the needs.

Despite findings pointing to the universal significance of need satisfaction, SDT acknowledges the importance of cultural diversity. Namely, it recognizes that the three needs may be emphasized to varying degrees in different contexts and there may be different means to accomplishing need satisfaction depending on cultural values, customs, and practices (e.g., Chen et al., 2015; Bao & Lam, 2008). For example, past research has suggested that students vary in their response to having personal choices (i.e., a strategy for supporting autonomy need satisfaction) depending on culture, with another close person choosing aspects of a learning task having the same or greater benefits for Asian and Asian-American students' intrinsic motivation and performance as students personally choosing (e.g., Iyengar & Lepper, 1999; Bao & Lam, 2008). It should be noted that the environmental affordance of choice or having independence are not synonymous with experiencing autonomy, though the two are correlated (e.g., Patall & Hooper, 2017). That said, this research suggests that how one may come to experience autonomy can vary depending on culture.

Other research points to cultural variation in psychological needs, albeit these findings both support and conflict with social constructivist views. For example, in line with the social constructivist perspective, Oishi et al. (1999)

found that autonomy need satisfaction was more predictive of life satisfaction in countries that were high (vs. low) in individualism. However, in another study comparing students in the U.K. (i.e., an individualist culture) and Hong Kong (i.e., a collectivist culture), researchers found that while teacher autonomy support was important for vitality and effort via need satisfaction for all students, it had a stronger positive association with students' feelings of competence in the Hong Kong sample (vs. the U.K. sample), and students' feelings of relatedness had a significant, positive association with student effort in the U.K. sample (but not for the Hong Kong sample) (Taylor & Lonsdale, 2010). With these conflicting findings and viewpoints, it is important to examine the associations between autonomy and relatedness need satisfaction and achievement-related outcomes in other diverse racial groups.

Latino and White American culture in the U.S.: exploring outside the east-west binary

Much of the research on cultural variation in psychological needs has focused on comparisons between Asian and white American or European samples (e.g., Chen et al., 2015). However, cultural diversity within the U.S. warrants an examination of these processes among different ethnic groups. In particular, Latino culture in the U.S., which blends collectivist and individualist values, offers a unique perspective on the role of culture in need satisfaction and student engagement (e.g., Krys et al., 2022). As an ethnic category, a Latino individual is defined as "a person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin regardless of race" (Census Bureau, 2021). Past research has shown that Latinos, on average, endorse collectivist norms at higher rates than white Americans and as strongly as individuals in East Asia (Krys et al., 2022; Oyserman et al., 2002). Cultural values like *familism* (i.e., the prioritization of familial duties and warm, supportive relations with nuclear and extended family), *simpátia* (i.e., willingness to conform and maintain harmonious relations with others), and *respeto* (i.e., respect for elders and authority) emphasize the importance of interdependence, social roles, and relational obligations with members of one's social network (e.g., Kim et al., 2009). Prior research reflects the importance of both relatedness and autonomy for Latino students. In the classroom, relatedness need satisfaction has been found to predict motivation, engagement, postsecondary retention, achievement, and emotional and psychological well-being for Latino students (e.g., Froiland et al., 2019; Faircloth & Hamm, 2005; Gehringer et al., 2021). Autonomy has been tied to important psychological and achievement-related outcomes like feelings of self-efficacy, ethnic-racial identity exploration, and

academic performance as well (e.g., Close & Solberg, 2008; Rivas-Drake et al., 2020).

White-American culture, on the other hand, has been shown to prioritize individualist norms (Oyserman et al., 2002). Generally considered a racial categorization denoting individuals from European origins, white individuals within Western cultures are described as being more culturally individualistic (Triandis et al., 1988). Empirical evidence supports this cultural orientation: Oishi and Diener (2001) found that the pursuit of personal goals (i.e., independent goal pursuit) predicted subjective well-being for white Americans (and not Asian Americans), while the pursuit of communal goals (i.e., interdependent goal pursuit) predicted subjective well-being for Asian Americans (but not white Americans).

As Latino students are underrepresented in STEM fields, it is crucial to explore how cultural factors influence their engagement in science (Riegle-Crumb & King, 2010). While Latino culture is unique from other collectivist cultures (e.g., East Asian) (e.g., Krys et al., 2022), its more collectivistic orientation, when compared to white American culture, provides additional insight into how culture shapes the relationship between autonomy and relatedness need satisfaction and student functioning. Thus, in the current study, we examined how these needs interact to influence white and Latino American student engagement in order to better understand the role of culture in shaping student engagement in U.S. science classrooms.

Interactive relationships among basic psychological needs

Finally, although SDT is clear on the assertion that all three needs are important to facilitating students' motivation and engagement (e.g., Jang et al., 2016), how these needs interact with one another remains less clear. Most research has focused on the unique or additive relationships between the three needs, often overlooking potential interactive relationships. However, need satisfaction tends to be correlated, suggesting dependencies across needs (e.g., Deci & Ryan, 2014). Thus, we would expect their combined associations with desired outcomes to often be greater than the sum of each independently. Some studies have begun to explore these interactions (e.g., Sheldon & Niemiec, 2006). Dysvik et al. (2013) examined the potential additive and interactive associations between basic psychological need satisfaction and life outcomes in a sample of Norwegian adults, as well as the importance of balance among each need. They found that autonomy and competence significantly positively interacted to predict intrinsic motivation. However, autonomy and relatedness significantly positively interacted

to predict intrinsic motivation in one study, but not a second, and competence and relatedness negatively interacted in one study but not a second. Vansteenkiste et al. (2006) found a significant interaction between autonomy and relatedness for measures of vitality and depression among Chinese students in Belgium, though the interaction was negative.

In sum, evidence on the interactive relationships among need satisfaction is mixed. Moreover, research has yet to examine the extent to which daily autonomy and relatedness need satisfaction interact to influence students' engagement in science, in particular, or explore the extent to which such interactive relationships might depend on students' cultural backgrounds.

The present investigation

According to SDT, the satisfaction of basic psychological needs is universally critical for student motivation and engagement in STEM. However, some research suggests that the relative importance of autonomy and relatedness need satisfaction may vary across cultural groups, with mixed findings (e.g., Close & Solberg, 2008; Iyengar & Lepper, 1999). This study aims to clarify the unique and interactive relationships between daily autonomy and relatedness need satisfaction and academic engagement among white and Latino high school science students in the U.S, and explore potential across these two groups.

While much research on need satisfaction has focused on student-level variables, less attention has been given to the relationship between daily fluctuations in students' psychological need satisfaction and their daily science engagement. However, prior findings have indicated the importance of examining daily fluctuations of need satisfaction, as the extent to which students feel autonomous and relatedness can change over time, even within a given day (e.g., Reis et al., 2000). Thus, we employed a 6-week-long daily diary study, asking students to report on their daily experiences of need satisfaction and engagement in science class across an instructional unit. By doing so, our design addressed the extent to which daily changes in autonomy and relatedness need satisfaction explained daily variation in student science engagement. Our research questions were:

1. To what extent do daily perceptions of relatedness and autonomy need satisfaction independently and interactively predict daily science engagement for Latino and white students?
2. Do the unique and interactive relationships between students' daily perceptions of relatedness and autonomy need satisfaction and daily science engagement differ for Latino and white students?

Testing three competing theories: universalist, value-based, and compensatory-based

Based on the conflicting theories and findings previously discussed, we tested three competing hypotheses regarding culture-based differences in the relationships between autonomy and relatedness need satisfaction and student science engagement respectively: (1) universalist, (2) value-based, and (3) compensatory-based.

Universalist hypothesis As psychological needs are assumed to be universally important, there will be no interaction between either relatedness or autonomy with ethnicity (i.e., Latino or white). Given that the needs themselves tend to be associated (Deci & Ryan, 2014), autonomy and relatedness are predicted to interact positively in their association with students' engagement across cultures.

Value-based hypothesis In line with a social constructivist perspective, the relationships between autonomy and relatedness need satisfaction and science engagement will differ as a function of what is valued by the broader culture. Relatedness need satisfaction will more strongly predict science engagement for Latino American students (vs. white students) as values of connectedness are more prioritized by Latino culture (vs. white American culture). Autonomy need satisfaction will more strongly predict science engagement for white students (vs. Latino students) as norms of independence and self-focused goals (rather than group goals) are more valued in white-American culture (vs. Latino culture). Given that relatedness may not be as highly valued for white Americans as Latino Americans (e.g., Krys et al., 2022), experiencing relatedness may be less likely to bolster the positive relationship between autonomy and engagement for white American students compared to Latino American students.

Compensatory-based hypothesis The relationships between autonomy and relatedness need satisfaction and student engagement in science will differ as a function of what needs are less emphasized by the broader culture, and thus, the experience of these psychological needs being satisfied in the classroom would prove more impactful. Relatedness need satisfaction will more strongly predict science engagement for white students (vs. Latino students) as relatedness may be less emphasized or attended to in white American culture (vs. Latino culture). Autonomy need satisfaction will more strongly predict science engagement for Latino students (vs. white students) as autonomy may be less attended to in Latino culture. From this perspective, we would not predict that autonomy and

relatedness would interact in their association with student engagement, as there may be little opportunity to further bolster the relationship between need satisfaction and engagement for a need that is already well attended to by one's broader culture.

In sum, in line with SDT claims that all three needs are universally essential to human thriving, we hypothesized that students' perceptions of daily relatedness to teachers and autonomy would have unique and interactive positive associations with daily science engagement for all students after controlling for time, prior engagement, and a variety of student and classroom characteristics. Regarding cultural variation, due to conflicting theories and findings from universalist and social-constructivist perspectives, we tested three competing hypotheses to explore the extent to which the independent and interactive relationships between autonomy, relatedness, and science engagement differed between white and Latino students.

Methods

Participants

The current study utilized a quantitative, multilevel modeling approach to analyze intensive longitudinal data from The Autonomy Support in High School Science project, which has been used in prior published work for research questions distinct from this study (e.g., see Patall et al., 2016). Participants for this study included 157 Latino and white high school students (52% female; 13 to 18 years of age) from 43 science classrooms across nine public high schools in the United States. In terms of students' reported ethnicity, 55% of our sample consisted of students who identified as exclusively Hispanic or Latino ($n = 87$) and 45% of our sample consisted of students who identified as exclusively white ($n = 70$). Approximately 38% of students qualified for free-and-reduced lunch ($n = 57$), with the majority being Latino students who qualified (53 Latino students; 4 white students). Approximately 38% of students were in 9 th grade ($n = 59$), 28% of students were in 10 th grade ($n = 44$), 19% of students were in 11 th grade ($n = 30$), and 15% of students were in 12 th grade ($n = 24$). Students who participated were asked to report on their daily experiences across a 6-week period between January 2012 and May 2014.

Each classroom was led by a different teacher; there were 43 teachers in our sample. Teachers' years of experience ranged from 0 to 40, with a mean of approximately 11 years. Teachers' ages ranged from 25 to 66 years old, with a mean of approximately 39 years old. The majority of teachers in our sample were white (31 out of 43) and female (31 out

of 43). One teacher was Black, 3 teachers were Asian, 4 were Hispanic/Latino, and 4 were of mixed race/ethnicity or another race/ethnicity that was not specified.

Procedures

We obtained permission from the two school districts encompassing the nine high schools before recruitment began. A convenience sample of teachers were recruited in large-group information sessions where the experimenters described the purpose of the study and explained how the daily diary method would work. Teachers who chose to participate selected the course and instructional unit they preferred the study to occur in. The research team encouraged teachers to try and select their most typical course with a diverse group of students. Teachers were discouraged in selecting a course based on what they believed were their best (or worst) performing group of students. Across the nine high schools, approximately 40% of the recruited teachers participated in the larger study.

Next, convenience sampling was used to recruit student participants by research assistants who visited high school classrooms in person. During these in-person visits, the study was described and both a parent information letter and consent documents were distributed in English and Spanish. Standard parent/guardian consent forms and child assent forms informed participants and their guardians about the nature of the study including the types of questions that students would be asked. A drop box was set up at the main office of the school, and students were asked to return signed consent forms in a sealed envelope to the drop box. After all consent forms were collected, students were randomly selected from a pool of volunteers, with 3 to 4 students participating from each class. Upon selection, student participants met with a research assistant for an orientation meeting. During this initial meeting, students practiced using the iPod Touch they'd be utilizing for the course of the study while completing a background survey that included questions on students' demographic information. During this meeting, students also discussed their school and personal schedule in order for research assistants to determine the ideal time for each participant to receive and complete their daily reports. Next, over a six-week period, students completed a baseline survey and completed subsequent daily surveys on their experiences of relatedness, competence, autonomy, intrinsic and extrinsic motivation, experiences of autonomy supportive and controlling instruction, and academic engagement and disaffection in science class after each class session using their Apple iPod Touch. Only need satisfaction and engagement measures were used for this study, along with demographic and course information. Students were emailed a survey during their first

non-instructional period following their science class session for them to complete during their "free" period. Students' number of scheduled science class sessions ranged from 11 to 17 and the range of completed daily surveys per student was from 1 to 17. Students were paid $5 for every survey they completed and received a $50 bonus if they completed all reports for when they were present in class. Teachers received $50 for participating in the study and schools received $100 for each participating teacher. All identifiable information was removed from the dataset following data collection to ensure participant anonymity and confidentiality.

Measures

Science engagement

Students' engagement in their science class was measured with 15 items adapted from the previously validated Engagement versus Disaffection with Learning Student Report (Skinner et al., 2009), the Metacognitive Strategies Questionnaire (Wolters, 2004), and the Agentic Engagement Scale (Reeve & Tseng, 2011). Students' behavioral and emotional engagement were measured using three behavioral and four emotional engagement items from the Engagement versus Disaffection with Learning Student Report that were adapted to the daily level. An example item for the behavioral and emotional engagement scales includes, "I worked as hard as I can in science class today" and "When I was in science class today, I felt good." Four items from the Metacognitive Strategies Questionnaire were adapted to measure students' daily cognitive engagement. An example of an item used to measure cognitive engagement is "I tried to connect what I was learning in science class today with my own experiences." Finally, four items from the Agentic Engagement Scale were adapted to measure students' daily agentic engagement. Items asked students about their ability to take initiative in their learning, such as "I let my science teacher know what I needed and wanted today." All items

asked students to rate the extent to which they agreed with statements on a 5-point Likert scale ranging from (1) not at all true to (5) extremely true.

To establish measurement invariance between white and Latino students for the engagement measure, we conducted multi-level, multi-group confirmatory factor analyses (CFAs) with the white student and Latino student samples. We ran a series of increasingly restrictive models to establish configural, metric, scalar, and strict measurement invariance. To compare MLR models, we conducted Satorra-Bentler scaled chi-square difference tests. CFI and RMSEA were utilized as the primary indices for model fit due to their widespread acceptance as robust indicators of fit for multi-group CFAs (Cheung & Rensvold, 2002). First, to establish configural invariance we removed one item from the agentic and cognitive engagement scales using a factor loading of 0.40 as a cutoff. The behavioral engagement subscale was also excluded due to low factor loadings (below 0.4) for Latino students. Removal of these items established configural, metric, scalar, and strict invariance across the student samples. Additionally, the changes in CFI and RMSEA were minimal, further supporting measurement invariance across groups. Model fit was good across models ($\chi^2 = 242.48–307.86$, $df = 122–163$; CFI ≥ 0.94, RMSEA ≤ 0.03; see Table 1). A composite engagement scale was created by averaging the updated daily agentic, cognitive, and emotional engagement scales ($\alpha = 0.76$). See Table 1 for more information on fit indices and Satorra-Bentler scaled chi-square difference test results for each model.

Daily relatedness need satisfaction

Relatedness need satisfaction was assessed at the daily level using two items adapted from the perceived relatedness subscale of the validated Activity-Feeling States (Reeve & Sickenius, 1994). These items included, "I felt close to my science teacher" and "I felt connected to my science teacher." Students rated the extent to which they agreed with statements on a 5-point Likert scale ranging from (1)

Table 1 Tests of measurement invariance across White and Latino student groups

Model	χ^2	df	CFI	RMSEA	Δ SBS χ^2	Δ df	p
Engagement							
Configural	242.48	122	0.95	0.03			
Metric	275.11	142	0.94	0.03	29.12	20	0.09
Scalar	307.86	162	0.94	0.03	4.14	20	0.99
Strict	296.90	163	0.94	0.03	1.43	1	0.23
Autonomy, Relatedness							
Configural	177.32	74	0.95	0.03			
Metric	196.23	90	0.95	0.04	9.61	16	0.89
Scalar	225.05	106	0.94	0.04	3.03	16	1.00
Strict	203.54	112	0.95	0.03	6.47	6	0.37

CFI = comparative fit index; RMSEA = root mean square error of approximation; Δ SBS χ^2 = change in Satorra-Bentler scaled chi-square

not at all true to (5) extremely true. The bivariate correlation for these two items was $r = .84$.

Daily autonomy need satisfaction

Students' autonomy need satisfaction in science class was assessed with six of nine items from the Perceived Self-Determination Scale (e.g., "I feel like learning was my own choice in science class today;" Williams & Deci, 1996). Students rated the extent to which they agreed with statements on a 5-point Likert scale ranging from (1) not at all true to (5) extremely true. The validity and reliability of the scale for cross-sectional research have been established in previous studies (Reeve & Jang, 2006). Three reversed items were dropped because reverse-coded items often exhibit weaker factor loadings and can detract from overall scale reliability and validity (Lindwall et al., 2012).

A series of increasingly restrictive multi-level multi-group measurement models were also compared to establish measurement invariance of the relatedness and autonomy need satisfaction scales across white and Latino student groups. The one-factor relatedness scale was tested alongside the one-factor autonomy scale for model identification purposes. All items loaded on the respective factors adequately (> 0.40) and no items were removed from either scale. Satorra-Bentler scaled chi-square difference tests were conducted to compare model fit, with results showing that configural, metric, scalar, and strict invariance across white and Latino groups was met. Model fit was good across models ($\chi^2 = 177.32$–225.05, $df = 74$–112; CFI ≥ 0.94, RMSEA ≤ 0.04). Additionally, the changes in CFI and RMSEA were minimal, further supporting measurement invariance across groups. Table 1 includes information on model fit indices and chi-square difference test results. We then created a scale mean from the six daily autonomy items for use in subsequent analyses ($\alpha = 0.87$), as well as a scale mean of the two relatedness items.

Multi-level analysis

To test our hypotheses, we estimated a three-level regression model in order to account for the nested design of our data set (i.e., day nested in student; student nested in classroom) and address the non-independence of our observations (Raudenbush & Bryk, 2002). The model included students' daily relatedness satisfaction, daily autonomy satisfaction, time (i.e., a linear class session variable where each session was consecutively numbered beginning with zero), and lagged science engagement (i.e., engagement from the previous day) as predictors at Level 1 (day level). In our study, the main reason student engagement in science class was expected to vary was because of their experiences of need

satisfaction during class sessions. Therefore, engagement from the prior class session (i.e., lagged engagement) was entered to control for possible carryover effects from one class day to the next (e.g., Reis et al., 2000). Including the prior class session's outcome value as a predictor allowed us to predict day-to-day changes in the outcome as a function of need satisfaction, as opposed to the overall level of the outcome (Cohen & Cohen, 1982).

Several variables were included at level 2 (student level): race/ethnicity (0 = white, 1 = Latino), gender (0 = male, 1 = female), free or reduced lunch eligibility (0 = not eligible, 1 = eligible), age, and prior exam score. Finally, class level (0 = advanced, 1 = grade typical) and class session (0 = fall, 1 = spring) were included at level 3 (class level). Daily relatedness and daily autonomy were student-mean centered around each student's own average score to delineate day-level effects from between-student effects. Time, lagged outcome, and all other student and class level covariates were grand-mean centered. To treat missing data, we used a maximum likelihood estimation procedure with robust estimates of standard errors (REML). Since adjacent residuals in repeated measures data may be correlated across measurement occasions, we specified an AR(1) correlated error structure (Bolger & Laurenceau, 2013).

To answer our research questions, the multilevel model included a three-way interaction between race/ethnicity (i.e., Latino or white), daily relatedness satisfaction, and daily autonomy satisfaction, and all two-way interactions between the three variables. The three-way interaction was not significant, so it was removed from the final model. Implications of the nonsignificant three-way interaction will be examined in the following sections.

Results

Preliminary analyses

We first calculated correlations among students' daily relatedness need satisfaction, daily autonomy need satisfaction, and daily science engagement to examine if expected relationships among these variables were evident. We calculated this by first group-mean centering all variables using student as the group to disaggregate within-student and between-student variation. As expected, we found a strong positive correlation between Latino students' daily relatedness and science engagement ($r = .72$). Similarly, daily autonomy was strongly positively correlated with science engagement ($r = .78$). As for white students, we found a strong positive correlation between their daily relatedness and science engagement ($r = .81$). Daily autonomy for white students was also strongly positively correlated with science

engagement (r=.80). Table 2 shows Ms, SDs, and correlations for daily autonomy and relatedness need satisfaction, science engagement, and demographic variables for Latino and white students.

One-way ANOVAs were conducted to examine baseline differences across Latino and white student groups for autonomy and relatedness. There were no significant differences in the baseline levels of autonomy ($F(1, 154)$ =0.20, p=.65) and relatedness ($F(1, 155)$ =0.33, p=.57). All subsequent models used group mean centered daily autonomy and relatedness variables as predictors, which are centered relative to an individual's mean autonomy and relatedness satisfaction across all days. Therefore, we can interpret the coefficients to represent an increase in engagement when students experienced greater autonomy or relatedness satisfaction relative to their own average, controlling for the previous day's engagement level.

Independent and interactive associations between psychological need satisfaction and science engagement

To answer our first research question, we estimated a three-level regression model to examine the extent to which white and Latino students' daily autonomy need satisfaction, daily relatedness need satisfaction, and their interactions predicted daily science engagement, controlling for time, prior class day engagement, and all other student and class level covariates (see Table 3). In line with our hypotheses regarding our first research question, we found that both daily autonomy (b= 0.35, p<.001) and daily relatedness (b= 0.22, p<.001) uniquely predicted students' daily science engagement when controlling for all other covariates. That is, on days when students felt more autonomy and connection to their teachers, their engagement in science class increased relative to the prior class day. Further, the association between daily autonomy need satisfaction and students' daily science engagement was stronger than the association between daily relatedness need satisfaction and daily science engagement. Moreover, we found a significant interaction between daily autonomy and relatedness need satisfaction on science engagement (b= 0.10, p<.001) as predicted. This significant interaction provides support for the interactive associations of autonomy and relatedness need satisfaction on white and Latino student science engagement. Simple slope analyses revealed that daily autonomy need satisfaction predicted an increase in engagement to a greater degree when daily relatedness to the teacher was high (b= 0.45, p<.001) compared to when it was low (b= 0.33, p<.001). Put differently, the positive relationship between feeling autonomous and student engagement in science class on a given day was bolstered when students felt connected to their teachers as well.

Table 2 Means, SDs, and correlations among aggregated daily variables and student demographic variables for Latino and White American students

Variables	M	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	M	SD
(1) Autonomy	2.84	0.92	---	0.74***	0.80***	-0.20***	0.31***	-0.09*	0.12***	0.07	0.29***	2.81	0.97
(2) Relatedness	2.51	1.17	0.61***	---	0.81***	-0.33***	0.19***	-0.07	0.19***	0.07*	0.22***	2.64	1.26
(3) Engagement	2.80	0.86	0.78***	0.72***	---	-0.22***	0.28***	-0.01	0.22***	0.13***	0.31***	2.83	0.90
(4) Sex	0.58	0.49	-0.17***	-0.10**	-0.07*	---	0.02	-0.01	-0.08*	0.13***	-0.06	0.50	0.50
(5) Age	15.71	1.20	0.13***	-0.08*	0.02	0.01	---	0.03	0.31***	0.01	0.26***	15.52	1.21
(6) FRL	0.66	0.47	0.09*	0.00	0.14***	-0.06	0.03	---	-0.15***	-0.08*	0.08*	0.06	0.23
(7) Prior Grade	78.91	16.67	0.14***	0.16***	0.21***	-0.03	0.12***	-0.09*	---	0.21***	0.08*	87.60	12.89
(8) Advanced	0.49	0.50	0.14***	0.15***	0.17***	-0.26***	-0.17***	-0.07*	-0.15***	---	-0.09**	0.53	0.50
(9) Session	0.69	0.46	-0.01	0.07*	0.03	0.21***	0.03	0.20***	0.08*	-0.36***	---	0.70	0.46

n= 801 to 888 reports. Ms, SDs, and correlations for Latino students are on the left-hand side and below the diagonal. Ms, SDs, and correlations for white students are on the right-hand side and above the diagonal. All correlations are significant at p<.001. For FRL (free and reduced lunch) status, 0= not eligible for free/reduced lunch and 1= eligible for free/reduced lunch. For advanced, 0= grade typical class and 1= advanced class. For student sex, 0= male and 1= female. For session, 0= fall semester and 1= spring semester. * p<.05, ** p<.01, *** p<.001

Table 3 Daily relatedness and daily autonomy need satisfaction predicting science engagement

Predictor	Engagement b(SE)	
Day Level		
Relatedness	0.22*** (0.02)	
Autonomy	0.35*** (0.03)	
Relatedness x Autonomy	0.10*** (0.02)	
Relatedness x Ethnicity	− 0.07* (0.03)	
Autonomy x Ethnicity	0.08* (0.04)	
Lagged Outcome	0.09*** (0.02)	
Time	0.00 (0.00)	
Student Level		
Ethnicity	− 0.10 (0.14)	
Age	− 0.07 (0.10)	
Sex	− 0.24* (0.11)	
Free/Reduced Lunch	0.14 (0.14)	
Prior Exam Grade	0.02** (0.01)	
Class Level		
Intercept	2.27*** (0.16)	
Advanced Class	0.34* (0.13)	
Session	0.27* (0.14)	
Random Effects	Variance	SE
Day (L1)		
Residual	0.13	0.01
Autocorrelation	0.13	0.05
Student (L2) intercept	0.33	0.06
Class (L3) intercept	0.05	0.05

Level 1 (daily reports) n= 686 to 687 reports. Level 2 (students) n= 75. Level 3 (classes) n= 35. For ethnicity, 1= Latino and 0= White. The time variable reflects the day of reporting across the 6-week instructional unit. The lagged outcome variable reflects the prior class session's value for the outcome. For student sex, 0= male and 1= female. For free and reduced lunch status, 0= not eligible for free/reduced lunch and 1= eligible for free/reduced lunch. For advanced class, 0= grade typical class and 1= advanced class. For session, 0= fall semester and 1= spring semester. b= unstandardized regression coefficient. Standard errors in parentheses. * p<.05, ** p<.01, *** p<.001

Differences in associations between need satisfaction and science engagement for Latino and White students

Pertinent to our second research question, we compared whether the independent and interactive relationships of autonomy and relatedness satisfaction on science engagement were statistically different between white and Latino students by testing two and three-way interactions among student race/ethnicity, daily autonomy need satisfaction, and daily relatedness need satisfaction. We did not find a significant three-way interaction between students' ethnicity (white or Latino), daily autonomy, and daily relatedness on science engagement, suggesting that, in line with the universalist hypothesis, the interactive relationship between autonomy and relatedness was not different across both

ethnic groups. The non-significant three-way interaction was therefore removed from the final model.

However, in line with the compensatory-based hypothesis, we found a significant interaction between daily autonomy need satisfaction and student race/ethnicity (b= 0.08, p<.05). Simple slope analyses revealed that there was a greater change in the daily science engagement of Latino students (b= 0.43, p<.001) as a function of experiencing daily autonomy compared to white students (b= 0.35, p<.001) in our sample. Further, we found a significant negative interaction between daily relatedness need satisfaction and race/ethnicity (b= −0.07, p<.05). Simple slope analyses revealed that there was a greater increase in the daily science engagement of white students (b= 0.23, p<.001) as a function of experiencing daily relatedness compared to Latino students (b= 0.16, p<.001) in our sample.

Discussion

The present investigation examined the extent to which Latino and white American students' daily autonomy and relatedness need satisfaction in science class independently and interactively predicted daily science engagement. We utilized daily diary survey data to account for daily fluctuations in students' experiences of autonomy, relatedness, and engagement to examine these relationships.

Results supported our hypotheses derived from self-determination theory for our sample of white and Latino students. We found that after controlling for student and classroom characteristics, daily autonomy and relatedness need satisfaction were positively associated with daily changes in science engagement, respectively, for both student groups. Further, the interactive associations of daily relatedness and autonomy need satisfaction on student science engagement was found for both student groups as well. Although there is debate around the universality of the three basic psychological needs, these findings provide additional evidence regarding the importance of both autonomy and relatedness need satisfaction for both white and Latino youth on a daily basis in science class. Some social constructivist research has suggested that relatedness need satisfaction should play a more significant role for the classroom functioning of Latino students, while autonomy need satisfaction should play a more significant role for white students. We did not find evidence of this. Rather, in line with the compensatory-based hypothesis, daily autonomy need satisfaction was more strongly related to science engagement for Latino students compared to white students. Relatedness need satisfaction was more strongly related to science engagement for white students compared to Latino students. However, despite this difference in these

independent relationships with engagement, the consistent positive interaction we found between needs in predicting engagement suggests that the simultaneous satisfaction of both needs predicts engagement more strongly than one alone for both student ethnic groups.

While these findings may seemingly stand in contrast with social constructivist views that stress the importance of cultural values regarding psychological need functioning, we do not see our findings as incompatible with such views. Students may benefit from the satisfaction of needs that are prioritized by their culture, but also benefit from the satisfaction of needs that are less emphasized and possibly, less consistently or strongly satisfied. White students in the U.S. are generally from more individualistic cultural backgrounds, which often emphasize notions of self-reliance and independence more so than the importance of relationships and community. Thus, we might expect that when one's culture emphasizes autonomy needs to a greater extent than relatedness needs, the satisfaction of relatedness in certain contexts may have stronger positive associations with important outcomes if it is not as consistently satisfied more broadly. In this study, we found that daily relatedness satisfaction had a stronger positive relationship with daily science engagement for white students compared to Latino students, suggesting that white students particularly benefit from relatedness satisfaction in school because their relatedness needs may be less consistently satisfied within their individualist culture. Likewise, we found that daily autonomy had a stronger positive relationship with daily science engagement for Latino students than for white students. This result suggests that Latino students particularly benefit from autonomy need satisfaction at school, perhaps because relatedness is more consistently emphasized and therefore, more consistently satisfied, in Latino students' cultural environments, while autonomy is less consistently satisfied. These findings suggest that the basic psychological needs are not in conflict with collectivist compared to individualist cultures, rather that the basic psychological needs are important, both through main and interactive associations, for student outcomes across cultural groups. Further, our findings may point to ways that students differentially and adaptively experience autonomy and relatedness need satisfaction in school depending on the cultural emphasis of these needs in their out-of-school contexts.

When considering our findings in relation to existing literature on the interactive relationships, some inconsistencies are apparent. For example, Vansteenkiste et al. (2006) found that autonomy and relatedness need satisfaction negatively interacted when predicting feelings of vitality/depression, such that autonomy better predicted these outcomes when

relatedness was low. We might view this as an alternative form of compensation that we predicted, where the impact of one need is particularly impactful when other needs have been neglected and are not satisfied. However, this stands contrary to our current findings, which indicate that high levels of relatedness enhance the relationship between autonomy and science engagement for students from both collectivist and individualistic cultures. One explanation for these opposing findings may be due to important cultural differences between study samples and their settings. Vansteenkiste et al.'s (2006) study focused on Chinese college students studying abroad in Belgium, while our current sample focused on Latino American high school students in the U.S. While both Chinese and Latino cultures have been shown to endorse collectivist values, past research has emphasized that Latino culture also endorses individualist norms to a greater degree than East Asian cultures. Moreover, these findings may reflect the particular context of studying abroad, a context that likely creates barriers for relatedness need satisfaction. As such, Vansteenkiste and colleagues (2006) findings may be reflecting functional coping for Chinese students studying abroad. In contrast, Latino and white students in our study were living and studying at home within communities of people with their same ethnicity and cultural values.

Overall, the current study highlights the importance of understanding the role of culture in the relationship between psychological need satisfaction and student science engagement, and we recommend that educators consider how students' cultural backgrounds impact the independent and interactive associations between the three basic psychological needs and engagement. Our findings point to both unique and interactive relationships between students' daily autonomy and daily relatedness for white and Latino American students' science engagement. To promote equitable outcomes, we suggest that teachers should emphasize both experiences for autonomy and relatedness and avoid putting autonomy and relatedness needs at odds with one another, for example, by emphasizing independent student choices at the expense of collaboration or using strong positive personal relationships between teachers and students as a rationale for limiting students' participation in shaping learning experiences. Teachers can support students' experiences of relatedness in the classroom context by fostering authentic relationships grounded in respect and valuing of one another (Ryan & Deci, 2017) and experiences of autonomy through a variety of strategies that emphasize taking students' perspectives to guide interactions and activities (e.g., Patall & Zambrano, 2019). Such support can help align teachers' instructional strategies with students' motivational needs in the classroom to better support students' achievement.

Limitations and future research

The current investigation has provided evidence that enhances our understanding of how daily autonomy and relatedness need satisfaction relate to changes in students' daily engagement in authentic, high school science classrooms. Our key findings further support SDT's assertion regarding the universality of the basic psychological needs. However, the differences exhibited across ethnic groups in our sample indicate the importance of further exploring cultural variation of these needs.

One of the strengths of the current investigation is the longitudinal, daily diary design which allowed us to control for prior levels of the outcome variable in order to model change from one day to the next. Further, this type of research design allows participants to respond to survey questions about their experiences in class in real time, rather than through retrospection, which has potential to reduce response inaccuracies due to recall errors (Bolger et al., 2003; Hufford, 2007). However, a few limitations exist. First, our analyses should not be taken to imply causation. Experimental designs that use random assignment to manipulate students' exposure to experiences of autonomy and relatedness would allow for causal claims, but also test slightly different questions about support for psychological need satisfaction rather than the experience of need satisfaction. Also, the daily diary research design has potential to induce participant reactivity. That is, it is possible that students' participation in the study led to increased awareness of the constructs they responded to daily, which may have altered their responses. To account for this limitation, we included the class session as a Level 1 covariate in the multi-level regression model. Results indicated that time spent in the study was not significantly associated with students' engagement.

Furthermore, although we would have preferred to examine our predictions across students from other ethnic, racial, and cultural groups, our sample demographics only allowed for an examination of Latino and white students, who made up 42% and 32% of our original sample, respectively. Thus, our findings may not be generalizable to other diverse student groups (e.g., Asian, Black), as well as regarding other subject domains (e.g., math, English). We recommend that researchers not only examine variation, particularly in interactive associations, between students from traditionally collectivist vs. individualist backgrounds, but also look at how students from diverse cultures may vary, as we note the findings of positive interactive relationships for Latino American students in this investigation conflict with findings from prior studies conducted with students from other collectivist cultures (e.g., Vansteenkiste et al., 2006). Moreover, we note that the students in this research were in school settings in which white and Latino students were the most well-represented groups in the setting. Future research might consider exploring whether results are generalizable to white and Latino American students who attend schools in which their racial/ethnic group is a minority of the student population. Finally, another limitation of the present research is the reliance on student self-report data, which may lead to response bias. We recommend that researchers utilize observational techniques to examine students' engagement in science class to further corroborate our findings.

Conclusion

In conclusion, this research contributes to the growing body of work exploring the role of basic psychological need satisfaction in students' functioning in STEM. Results suggested daily autonomy and relatedness need satisfaction predicted an increase in students' daily science engagement for both Latino and white American students, and students' relatedness to teachers strengthened the positive relationship between autonomy need satisfaction and science engagement. We also found that daily relatedness was more strongly associated with an increase in daily science engagement for white American students, and that daily autonomy was more strongly associated with an increase in daily science engagement for Latino American students compared to their white peers. These findings have important implications for how teachers can tailor instructional strategies to best suit the needs of diverse students and support efforts to boost STEM engagement in high school students. Continuing to explore how relative differences in cultural emphasis on autonomy and relatedness needs affects the differential importance of students' psychological needs in school has potential to illuminate practices that strengthen students' motivation and engagement with science.

Data availability Data can be made available from the corresponding author upon reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Informed consent Informed consent was obtained from all individual participants (and their legal guardians) included in the study.

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