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Supporting and Thwarting Autonomy in the High School Science Classroom

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ABSTRACT

This investigation examined relations between adolescent students' daily and cumulative perceptions of teachers' practice and their experience of autonomy. Two-hundred and eighteen high school science students in 43 classes participated in a 6-week diary study. Multilevel modeling results suggested that perceptions of 8 out of 9 practices predicted a change in students' daily autonomy. Results also revealed that autonomy-relevant practices interacted with time, each other, and characteristics of students and classrooms. Implications are discussed.

KEYWORDS

autonomy support; autonomy thwarts; teaching practice; psychological needs; motivation; diary method

Teachers face a daunting challenge. Every instructional session, they must attempt to inspire students to deeply engage in course material and activities to facilitate learning. The most ambitious teachers attempt to cultivate students' motivation to continue learning about the subject matter beyond the current lesson and into the foreseeable future. With these goals in mind, creating a motivationally supportive environment is a central component of teachers' practice.

Indeed, there is little doubt that the environments that teachers create in their classrooms and the motivational strategies they employ can have profound effects on students' achievement motivation, engagement in the classroom, and performance on schoolwork (e.g., Eccles, 2004; Furrer & Skinner, 2003; Reeve, 2009). Of particular importance, motivation research has converged on the finding that teachers who engage in practices that are supportive of students' experiences of autonomy such as provisions of choice, rationales for the importance of the task, and structuring activities around students' personal interests facilitate student motivation and adaptive classroom attitudes and activity (e.g., Assor, Kaplan, & Roth, 2002; Reeve & Jang, 2006; Reeve, Jang, Carrell, Jeon, & Barch, 2004; Patall, Dent, Oyer & Wynn, 2013). Conversely, teachers who engage in controlling practices that thwart students' experiences of autonomy such as commands that demand conformity, controlling rationales, suppression of student expression, and requiring instructional activities that are perceived as meaningless or uninteresting may diminish motivation and engagement (e.g., Assor et al., 2002; Bartholomew, Ntoumanis, Ryan, Bosch, & Thøgersen-Ntoumani, 2011; De Meyer et al., 2014; Reeve & Jang, 2006).

However, shortcomings in the research on autonomy-relevant teaching—including the limited attention to individual practices, limited research in a classroom context beyond single survey cross-sectional designs, infrequent assessment specifically of students' personal experience of autonomy, and limited consideration for the characteristics of students or their classrooms—have restricted the understanding of how individual teaching practices relate to students' experiences of autonomy in authentic classrooms on a daily basis and over time. Moreover, understanding the nature and effects of autonomy support in the high school science classroom, in particular, is important for several reasons. Namely, focusing research on high school is useful, given that theory and evidence suggests that the development of and

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support for autonomy is essential for optimal social and psychological functioning of adolescents (e.g., Blos, 1979; Steinberg & Silverberg, 1986; Eccles, 2004; McElhaney, Allen, Stephenson, & Hare, 2009). Focusing research on science education during high school is also useful given evidence pointing to declines in motivation and engagement in adolescence (e.g., Lepper, Corpus, & Iyengar 2005; Martin, 2009) and for science fields in particular (e.g., Gottfried, Fleming, & Gottfried, 2001; Maltese & Tai, 2011), as well as the increasing demand for individuals with knowledge in the areas of science, technology, engineering, and mathematics (STEM) in the current global marketplace (e.g., Bureau of Labor Statistics, 2011; National Science Board, 2010) relative to the modest number of students who pursue STEM careers (Organisation for Economic Co-operation and Development, 2006). Finally, a number of student and classroom factors, including the students' gender, ethnicity, prior achievement, or the specific content of the science course, may influence students' perceptions of the environment and subsequent motivational response in ways that are specific to the science domain (e.g., Sinatra, Heddy, & Lombardi, 2015). This makes it all the more essential for researchers to focus specifically on science classrooms so that this science-specific heterogeneity can be explored.

Given these considerations, in this investigation, we conducted a diary study with high school science students and teachers over the course of a 6-week instructional unit. The main goals of this investigation were: (a) to explore how students' experience of autonomy and perceptions of autonomy-relevant practices change over the course of an instructional unit; (b) to examine the relations between a set of perceived teaching practices, routinely identified as autonomy-relevant, with students' daily and cumulative experiences of autonomy in authentic high school science classrooms and the extent to which such relations may change over the course of an instructional unit; (c) to explore the extent to which those links between perceived teaching practices and autonomy are moderated by student or classroom characteristics, including students' sex, ethnicity, socioeconomic status (SES), and prior level of academic achievement, or science class content and level, and (d) to examine how the perceptions of individual practices combine and interact in their relations with science students' daily and cumulative experiences of autonomy. Going beyond examining links between perceived practice and the experience of autonomy for individual students or classrooms of students, the chosen design—in which students' perceptions of teacher practice and experience of autonomy were assessed repeatedly over days—provided an opportunity to collect strong evidence regarding the predictive role of perceived teacher practice in explaining changes in autonomy from one day to the next.

The basic psychological need for autonomy and autonomy-relevant teaching

Autonomy reflects the experience that one's behavior is volitional and self-endorsed, emanating directly from one's personal understanding of the self, rather than external forces (Ryan & Deci, 2000; Su & Reeve, 2011). The experience of control is the logical opposite of autonomy, reflecting the perception that behavior is coerced by an external force (e.g., by a teacher's directive or an offer of a reward), is done out of feelings of pressure, obligation, or guilt, or is done due to a lack of choice.

According to self-determination theory, autonomy is central to optimal motivation, well-being, learning, and achievement. This is because autonomy as one of three fundamental needs that underlie such functioning, along with the needs for competence and relatedness (e.g., Ryan & Deci, 2000). Autonomy support has been linked with intrinsic motivation, engagement, and achievement (e.g., Reeve & Jang, 2006; Grolnick, Ryan, & Deci, 1991; Lepper, Corpus, & Iyengar, 2005); autonomy frustration has been linked with greater amotivation or external motivation and poorer engagement and achievement (e.g., Assor, Kaplan, Kanat-Maymon, & Roth, 2005; Soenens, Sirens, Vansteenkiste, Dochy, & Goossens, 2012; Assor, Vansteenkiste, & Kaplan, 2009). Given these links, an important question for educational psychologists has been how, exactly, teachers can support students' experiences of autonomy in the classroom.

In fact, the need for autonomy (as well as the needs for competence and relatedness) can be supported or thwarted by the environment. Broadly, autonomy support in the classroom context reflects a motivational approach in which teachers identify, nurture, and develop students' inner motivational resources so that students perceive themselves as the initiator of their actions (Reeve, 2009). An autonomy-supportive teacher strives to vitalize students' experience of autonomy so that it may play a greater role,

as opposed to teacher pressure and external consequences, in energizing and directing students' classroom activity. Although many teacher behaviors can be involved in creating an autonomy-supportive classroom environment, according to the self-determination theory framework, autonomy-supportive teachers are conceptualized as taking their students' perspectives, offering choices, and encouraging students to take initiative in their work, and work in their own way at their own pace. Autonomy-supportive teachers rely on noncontrolling language, acknowledge and accept students' negative feelings about course work, and provide time for students to express their opinions and ask questions. Although they attempt to structure activities around students' interests or include fun elements in lessons whenever possible, they also provide meaningful and personally relevant rationales to explain the usefulness of even so-called boring course activities, and give encouraging feedback when students become frustrated or struggle (see Reeve & Jang, 2006, Reeve, 2009; or Su & Reeve, 2011 for a review of autonomy-supportive practices).

In contrast, teachers using controlling instructional practices that thwart autonomy are essentially dismissive of students' perspectives and pressure students to think, act, or feel in particular ways (Reeve, 2009). Although autonomy support and control have often been conceptualized as being on opposite ends of a continuum, research has increasingly suggested that controlling (or autonomy-thwarting) behaviors cannot by equated with infrequent acts of autonomy support, and rather, exert effects that are independent of autonomy support (e.g., Bartholomew et al., 2011). Although relatively few studies have addressed the effects of controlling teacher behaviors, research has frequently conceptualized autonomy-thwarting teaching behavior to include explicitly controlling language (e.g., "you must" or "you should"), commands that pressure students to act in teacher-sanctioned ways, rationales that emphasize the external consequences of compliance, suppression of students' questions and opinions, and the assignment of activities that appear meaningless and uninteresting (e.g., Assor et al., 2002; 2005; Reeve, 2009; Reeve & Jang, 2006).

Despite substantial progress made in research focused on understanding the effects of autonomy-supportive and controlling teaching behaviors, few studies have simultaneously examined both sets of practices within an authentic high school classroom environment o uncover those practices most strongly linked with high school students' experiences of autonomy. Moreover, theory and evidence has provided mixed support regarding whether one or a select number of practices may be more central to autonomy support relative to others. In an early laboratory study exploring the relative contributions of providing a rationale regarding the importance of an uninteresting task, acknowledging negative feelings, and using noncontrolling language, results suggested the presence of any two or more practices had a positive effect on intrinsic motivation of college students, but no one practice emerged as effective on its own or more powerful than the others (Deci, Eghrari, Patrick, & Leone, 1994). Notably, this study was outside the classroom context and excluded choice provision, a well-researched strategy that is commonly associated with autonomy support (e.g., Patall, Cooper, & Robinson, 2008).

In contrast, other research has suggested that some practices may be more powerful than others. Assor and colleagues (2002) found that teachers' rationales regarding the relevance of activities emerged as the strongest predictor of positive emotion and engagement, but the provision of choices and perspective-taking were less predictive. Still other research suggests that choice provision may be an especially powerful component of autonomy support, particularly when the outcome of interest is autonomy need satisfaction (as opposed to other more distal motivational outcomes like intrinsic motivation and engagement). This is particularly true when the provision of choice includes teachers allowing students to choose how they work and providing encouragement for working in their own way (Reeve & Jang, 2006; Patall et al., 2013). Even given the extensive evidence generally supporting the positive effects of choice provision, research has also suggested that the effects of choice provision may be influenced by a number of factors, including the context in which choices are administered, the students' cultural background, and students' perception of competence (e.g., see Patall & Hooper, in press, for a review)—making it important to explore interactions between choice provision and student and classroom characteristics.

In addition, little (if any) research has explored the links between daily fluctuations in perceptions of teachers' practices and students' experiences of autonomy. That is, the experience of autonomy is likely to fluctuate from one day to the next and from one setting to the next (e.g., Reis, Sheldon, Gable, Roscoe, &

Ryan, 2000). That is, whereas person- (and classroom-) level effects ask what can perceived teacher practices, averaged over time, explain about why one student (or one classroom of students) feels autonomous but another does not, day-level effects ask what perceived teacher practices are associated with a student feeling more or less autonomous relative to his or her own baseline. We predict that even minor variations in perceptions of the classroom environment from one day to the next can influence daily fluctuations in autonomy need satisfaction. Further, we also predict that perceived teacher practices that have beneficial effects on any particular day may accumulate over time and lead to even stronger cumulative experiences of high autonomy for individual students or the class as a whole over time. However, the research designs that have been used to examine autonomy-relevant teaching practice have not allowed investigators to explicitly test these predictions. To address these issues, our investigation examined students' perceptions of a relatively comprehensive set of autonomy-relevant teaching practices over time in high school science classrooms.

Finally, little is known about how teachers may fluctuate in their use of autonomy-relevant practice over the course of an instructional unit and whether the relations between practices and autonomy vary over the course of an instructional unit. It seems likely that teachers may naturally use certain practices at particular points in the instructional unit and students' perceptions of practice are likely to reflect that. For example, although rationales regarding the personal importance or utility of course material may be useful early on in an instructional unit, they may become redundant or unnecessary as instruction on the same topic progresses. In contrast, consideration for students' negative emotions, opinions, questions, and opportunity for choosing may become particularly relevant as students gain more experience and expertise with the content, as the content becomes more difficult and as summative evaluation points loom closer. As such, it seems likely that while some practices increase in their perceived use over time, others decrease.

For similar reasons, the daily relations between perceptions of practices and autonomy seem likely to vary over time in a classroom as instruction progresses. Practices such as providing a rationale or working student interests and preferences into activities may be a particularly powerful strategy for supporting autonomy at the beginning of an instructional unit, when material is first being introduced and justification is needed to garner students' investment in learning the topic. However, as an instructional unit progresses and students gain more expertise for content of the unit or experience negative emotions as test time approaches, strategies like being considerate of students' negative emotions or providing opportunities for choices, questions, and feedback may be particularly effective for creating and reinforcing feelings of autonomy. Along the same lines, practices that are likely to thwart autonomy, such as controlling messages, suppression of student perspectives, and use of uninteresting or meaningless activities, seem likely to be experienced as particularly restrictive early on in an instructional unit, when material is first being introduced and students are trying to understand the reasons for investing in learning. In contrast, such practices may not be experienced as quite as controlling later in a unit, as the emphasis in instruction shifts from learning and discovery to establishing and demonstrating mastery. The current design in which perceptions of the environment and autonomy were assessed repeatedly over time allowed us to examine change in perceptions of autonomy-relevant teacher practices over time, as well as variation in their links with autonomy, in exploratory analyses.

Variation across science students and science classrooms

A number of student and classroom factors may be particularly important to take into consideration when exploring students' perceptions of the classroom environment and its effects for motivation, engagement, and learning in the domain of science (e.g., Sinatra et al., 2015). Groups such as women, Black and Hispanic individuals, and low-income students have typically been underrepresented in STEM fields (e.g., see Riegle-Crumb & King, 2010; Sinatra et al., 2015 for discussion), and research suggests that students of various genders, ethnicities, and socioeconomic statuses are not equally interested in pursuing STEM fields (e.g., Lichtenberger & George-Jackson, 2013). Moreover, not all science fields are equally attractive to students. Research has long indicated that students have higher course enrollment and more favorable attitudes toward biology, relative to other science fields like physics or

chemistry (e.g., Whitfield, 1980; Osborne, Simon, & Collins, 2003; Haussler & Hoffman, 2002), with women being particularly likely to favor biology topics (Su & Rounds, 2015).

Taken together, this suggests that it is important to consider the role of students' gender, race/ethnicity, socioeconomic status, and achievement history in science, as well as the nature and content of science courses, in research focused on students' psychological experiences in the science domain. However, research to date on autonomy-relevant classroom practices has rarely examined the role of these student and classroom characteristics. As such, we had limited information on which to base predictions regarding the role of student and course characteristics in the relations between perceived teacher practice and autonomy. Even so, we predicted that practices intended to support autonomy may play an especially important role in bolstering the autonomy of female, Black, Hispanic, low-income, and low-achieving students. These are individuals who have traditionally been underrepresented in science fields, and thus may benefit more from the psychological support within the classroom context. We also expected that practices intended to support autonomy may play an especially important role in supporting the experience of autonomy among students in required grade-typical and physical science, as opposed to advanced or elective and biological science courses, given the greater autonomy and personal interest that students typically already bring with them in advanced and biological science courses. In contrast, controlling practices may be particularly detrimental to students who typically identify with the science domain (e.g., Caucasian and Asian boys, high-income students, students in advanced classes) and expect a certain amount of autonomy within science coursework. Given these considerations, we included a variety of student and class characteristics as control variables and moderators of the relations involving perceptions of teacher practice and experience of autonomy.

Additive versus interactive effects of autonomy support and control

Another related matter that has been left relatively ambiguously addressed in the literature is the extent to which components of autonomy-relevant teaching may yield stronger or weaker effects, depending on whether they are administered in combination. As previously described, self-determination theory and some empirical research supports a Gestalt view of autonomy support, suggesting that autonomy support is most effective when administered in clusters of practices (e.g., Deci et al., 1994). Even assuming that supportive and thwarting practices do, indeed, combine in an additive fashion to influence experiences of autonomy, the possibility that the effect of any one teaching practice may be enhanced or diminished depending on the presence of others has yet to be fully addressed, in part because of the scarcity of classroom-based research simultaneously examining the components of autonomy-relevant teaching. In fact, to the best of our knowledge, interactive effects among individual components of autonomy-relevant teaching have not been explored, despite this implicit Gestalt assumption that components are most beneficial when they occur in concert. Thus, this study seeks to fill this gap by exploring how individual practices combine and interact to affect daily and cumulative experiences of autonomy. In line with self-determination theory, we expect that positive effects of any one supportive practice will be enhanced when a second is also high. Likewise, we expect the negative effect of any one controlling practice will be heightened when a second controlling practice is also high.

However, our predictions about how supportive practices might interact with controlling ones is more uncertain. One possibility is that the presence of a controlling practice might dampen any positive effects of the supportive practice. That is, in the context of controlling practices, autonomy support may be experienced by the student as ineffective or insincere. Conversely, and more desirably, any negative effects of controlling practices may be dampened by the presence of an autonomy-supportive practice. Alternatively, a contrasting interactive effect might emerge such that when students perceive their teachers to engage in a controlling practice, the link between autonomy-supportive practices and autonomy is heightened and, likewise, the negative link between controlling practices and autonomy is minimized in the presence of autonomy-supportive practices. That is, autonomy-supportive strategies may seem even more supportive (and controlling practices less controlling) when they are contrasted with thwarting (supportive) strategies.

This study

This study seeks to contribute to the small body of classroom research that has examined the components of autonomy support and autonomy thwarting by examining the links between perceptions of specific teacher practices and students' experiences of autonomy. With this study, we attempt to address some of the limitations in prior research, including the lack of data on the relations between individual practices and autonomy from real-life classrooms in high school science classrooms, as well as the relatively unknown role of time, level of analysis, and various student and classroom characteristics. To address these limitations, our investigation made use of a diary method that repeatedly assessed student perceptions of high school science teachers' practices and student experiences of autonomy for every science class across a 6-week instructional unit. This design extends evidence based on experimental and correlational research by providing an opportunity to examine the unique effects of perceptions of naturally-occurring teaching practices on any given day and over time within authentic high school science classrooms, while controlling for the students' experience of autonomy on the prior class day. As such, the daily-level relations can be interpreted as changes in students' experience of autonomy experience since the last time they were in class as a function of corresponding changes in students' perceptions of classroom teaching practice on that day. By aggregating students' perceptions of teaching practice across days, this design also allows us to examine the student-level relationship between perceived teacher practice and autonomy across the instructional unit. That is, we can examine the relationships between individual students' cumulative perception of teaching practices and their cumulative experience of autonomy across the six weeks. Likewise, by aggregating students' perceptions of teaching practice across students and days, this design allows us to examine the classroom-level relationship between perceived teacher practice and autonomy across an instructional unit. That is, we can examine the relationships between students' perceptions of teaching practices and their cumulative experience of autonomy for the class as a whole. Second and importantly, this design also allowed us to examine whether practices interact with time, each other, and characteristics of the student or the class—questions that have been neglected until this point despite reasons to believe that interactions are likely.

Thus, in sum, we sought to examine the following questions:

1) Does the experience of autonomy and student perceptions of potentially autonomy-relevant practices change over the course of an instructional unit?
2) To what extent are students' perceptions of teaching practices routinely identified as autonomy-relevant related to students' experience of autonomy in an authentic high school science classroom, both on a given day and cumulatively over time and students, and do these relations change during the course of an instructional unit?
3) Are the links between perceived teaching practices and autonomy moderated by student or classroom characteristics, including students' sex, ethnicity, socioeconomic status, and prior level of academic achievement, or science class content and level?
4) How do perceptions of individual teacher practices interact in their relations with science students' daily and cumulative experiences of autonomy?

We expected that all nine perceived autonomy-relevant practices we identified (choice provision, consideration for student interests and preferences, rationale provision, question opportunities, consideration for negative affect, encouraging and informative feedback, controlling messages, suppression of student perspectives, and uninteresting activities) would be related to students' experience of autonomy at the daily, student, and teacher levels, with stronger effects emerging when practices were aggregated over time. However, we also expected that the provision of choice and opportunities for students to work in their own way would emerge as the strongest predictors of student autonomy in the high school science classroom across all levels, despite mixed evidence (see Katz & Assor, 2007; Patall, 2013, Patall et al., 2013 for discussion). This is based on our assertions that choice is, on average, essential to autonomy support and, furthermore, that feeling a sense of choice is part of the very definition of autonomy. We also expected that effects of any one perceived supportive (or thwarting) practice would be bolstered when a second supportive (or thwarting) practice was also high. However, we were unsure whether supportive practices would bolster or mitigate thwarting practices, and vice versa. Finally, there was little existing

evidence or theory on which to base predictions about the changes in perceptions of practices across the 6 weeks, changes in their relations with student autonomy over time, or interactions with student and classroom characteristics. As previously discussed, we suspected that the patterns of interaction would likely be quite specific to each individual practice.

Methods

Participants

Participants were 218 urban and suburban high school science students (13 to 18 years of age; 55% female; at least 42% eligible for free or reduced-price lunch) from 43 science classrooms across eight public high schools in the southwest region of the United States. Students participated in a diary study in which they were asked to provide reports of their experiences after every science class during a 6-week instructional unit between January 2012 and May 2014 (2,306 total reports across all students). Forty percent of students were in the 9th grade, 25% were 10th graders, 18% were 11th graders, and 17% were 12th graders. Thirty-two percent of the students across these classes were Caucasian, 40% were Hispanic/Latino, 10% were Black, 4% were Asian or Asian American, and 13% were of mixed ethnicities or another ethnicity. Two students did not share their ethnicity.

Each of the 43 classrooms was led by a different science teacher. The majority of the science classrooms were required survey science courses such as biology, chemistry, and physics (grade-typical biology: $n = 7$, pre-AP biology: $n = 8$, grade-typical chemistry: $n = 5$, pre-AP chemistry: $n = 5$; grade-typical physics: $n = 6$, pre-AP physics: $n = 3$, and integrated physics and chemistry: $n = 3$). A small number of courses covered advanced elective topics in the biological (e.g., anatomy: $n = 2$, aquatic science: $n = 2$), or physical sciences (e.g., engineering: $n = 1$, environmental systems: $n = 1$). All of the units in the science courses were consistent with state standards for science classrooms, which is the state's curriculum document. Examples of topics covered in science courses included cell structure and genetics in biology, how atoms form ionic and covalent bonds in chemistry, or the impact of human growth on aquatic systems in aquatic science. A wide range of pedagogical practices (i.e., group work, formative and summative assessment, classroom discussions, research projects, lab experiments, etc.) were used across the unit within these science classrooms. The number of students participating in the study from each class ranged from three to six. Approximately 47% of students were enrolled in a grade-level survey biology (16%), physics (15%), or chemistry (10%) or a combined physics and chemistry (6%) course and 38% were enrolled in an advanced (i.e., pre-AP) survey biology (19%), chemistry (12%), or physics (7%) course. The remaining 15% students were enrolled in one of the specialty topic science courses mentioned previously. Across grade-typical and advanced course levels, approximately 44% of students were in a biological sciences course, with the remaining 56% enrolled in a physical sciences course.

Participation was voluntary and students under the age of 18 secured parental permission to participate. In recruiting students, the goal was to randomly select five student participants from each of the 43 classes among those students that volunteered to participate. In the majority of classrooms (38 of 43), at least five students volunteered to participate and students were randomly selected in cases where more than 5 volunteers were available. In some classes, less than five students volunteered. Four students participated in each of 5 classes. In one class, just three students participated. To accommodate for the reduced student-level sample size in six of the 43 classes, we allowed a total of six students to participate in each of 10 other classes. Five students participated in each of the other remaining classes (27). Students were paid $5 for every survey completed and received a $50 bonus for completing all reports for which they did not have an excused absence from class.

Teachers' years of experience ranged from 0 to 40 ($M = 10.45$, $SD = 9.62$). Teachers were 25 to 66 years of age ($M = 38$; $SD = 12.29$). The majority of teachers (30) were Caucasian and female (31). One teacher was Black, three were Asian American, four were Hispanic/Latino, and five were of mixed ethnicities or another ethnicity. Teachers received $50 for their participation in the study and schools received $100 for each participating teacher.

Procedure

Recruitment of participants for this study occurred in stages. Teachers were recruited in group information sessions following obtaining permission from the two southwestern school districts, as well as individual high school principals, vice principals, and science chairs at each of the eight schools. Teachers were informed of the purpose and methods involved in the study and were allowed to select both the course that would participate in the study and the instructional unit during which the study occurred among those between January 2012 and May 2014.

Student participants were recruited via in-person classroom visits in which the study was described and a parent information letter and consent documents in both English and Spanish were distributed. Students were asked to return signed consent documents in a sealed envelope to a box located at the main office of the school.

Upon recruitment and selection, participating students first met with a member of the research team to learn about their responsibilities as a participant, as well as to receive and set-up an Apple iPod touch used to complete surveys for the duration of the diary study. During this initial meeting, student participants practiced using the iPod by completing a short background survey regarding their age, grade level, sex, ethnicity, free or reduced price lunch status, and science course grade in the prior grading period. For 22 students, information was not provided on one of these demographic variables, most often information was missing regarding the students' free or reduced price lunch status. In addition, this initial meeting was used to establish the students' school and personal schedule and determine the ideal time for the student to receive and complete daily reports.

Following the start of the 6-week instructional unit, students were e-mailed with a survey asking them to respond to questions about their teachers' practices and their experiences of autonomy in class after each class session for the unit during their first free period (i.e., noninstructional time). All questionnaires were programmed using Qualtrics and completed by students online using the Apple iPod touch provided by the researchers. All classes met on a block schedule, approximately every other school day. The number of report opportunities varied depending on the class and number of class sessions that occurred in the particular 6-week instructional unit. The number of scheduled class sessions ranged between 11 and 17, with classes having between 8 and 17 opportunities to report on class experiences as a result of various disruptions to class sessions (Median = 14). In two classes, there were eight reporting opportunities, in two classes there were nine, in six classes there were 10 opportunities, in seven classes there were 12 opportunities, in five classes there were 14 reporting opportunities, in eight classes there were 15, in six classes there were 16, and in seven classes there were 17 reporting opportunities. Daily report surveys remained available for students to complete until the next class session began. The number of reports that student participants completed across the instructional unit ranged from 1 to 17 ($M = 11$; $SD = 3.73$; Mode = 10). Fifty-four students did not miss any reports. Another 118 students missed between 1 and 4 reports. Thirty-six students missed between 5 and 10 reports. Nine students missed between 11 and 14 reports. Three students had as few as two reports and just one student had a single report.

Measures

Student reported daily perceived autonomy

Students' daily perceived autonomy in science class was assessed with six of nine items from the perceived self-determination scale (e.g., "I felt I did what I wanted to be doing in my science class today;" Reeve, 2002). Reversed items were dropped because they typically load most weakly in factor analyses. Students rated the extent to which they agreed with each item on a 5-point Likert scale ranging from *not at all true* (1) to *extremely true* (5). The validity and reliability of the scale for cross-sectional research have been established in previous studies (Reeve et al., 2003; Reeve & Jang, 2006). However, as reported in the following, we conducted multilevel factor analyses and reliability analyses to confirm that this abbreviated measure was appropriate for our daily diary context.

Student reported daily teacher practices

Students' perceptions of the extent to which the teacher used practices intended to support or thwart autonomy on a given day was assessed with a measure designed explicitly for use in this diary study and based on prior measures used in cross-sectional research (Patall et al., 2013; as well as Assor et al., 2002; 2005; Belmont, Skinner, Wellborn, & Connell, 1992; Connell, 1990; Katz, Kaplan & Gueta, 2009; Reeve, Jang, Carrell, Jeon, & Barch, 2004; Reeve & Jang, 2006; Reeve, 2006; Wellborn & Connell, 1987). The measure contained 31 items to assess seven supportive daily practices and three thwarting daily practices hypothesized to be related to autonomy need satisfaction and motivation based on prior research (e.g., Assor et al., 2002; 2005; Deci et al., 1994; Patall, et al., 2013; Reeve & Jang, 2006; Reeve, 2009). Supportive practices included (a) provision of choices (3 items; e.g., "My teacher provided options for the kinds of assignments or activities I could do today"); (b) opportunities for students to work in their own way (3 items; e.g., "My teacher allowed me to choose how to do my work in the classroom today"); (c) rationales regarding the usefulness and importance of course material (4 items; e.g., "My teacher explained how what we were learning today is important"); (d) opportunities for students to express negative affect (2 items; e.g., "My teacher was open to hearing criticism or complaints about activities today"); (e) student question opportunities and responding (3 items; e.g., "My teacher acknowledged and responded to my questions in class today"); (f) consideration for student opinions, preferences, and interests (5 items; e.g., "My teacher structured class activities today around my interests"); and (g) encouraging and informational feedback (3 items; e.g., "My teacher gave suggestions when I struggled with course work today"). Thwarting teacher practices included (a) controlling messages (3 items; e.g., "My teacher was strict about me doing everything in his or her way today"), (b) suppression of student perspectives (3 items; e.g., "My teacher stopped me from expressing my opinions in class today"), and (c) uninteresting activities (2 items; e.g., "My teacher forced me to do uninteresting activities in class today"). Students rated the extent to which they agreed with each item on a 5-point Likert scale ranging from *not at all true* (1) to *extremely true* (5). Items included in this investigation were selected and retained from a larger set based on initial pilot factor analyses of daily reports. As previously mentioned, we conducted multilevel factor analyses and reliability analyses to confirm the suitability of this measure for our purposes.

Multilevel exploratory factor analysis

To assess the factorial validity of daily measures of perceived teacher practices and perceived autonomy, we conducted three multilevel exploratory factor analyses (ML-EFA; Roesch et al., 2010) using the oblique geomin rotation and a robust maximum likelihood estimation procedure (i.e., MLR) in Mplus 6.12 to examine both day and student level (by computing the mean across days for each student) factor structures. The TYPE = COMPLEX command in Mplus was used to account for the clustering at the classroom level. ML-EFAs were conducted separately for perceived autonomy, supportive teacher practice, and thwarting teacher practice items.[1]

To summarize, results suggested that at both day and student levels, a one factor structure fit the perceived autonomy items best, a six factor structure fit the supportive teacher practice items best, and a three factor structure fit the thwarting teacher practice items best. Inspection of model fit indices (for all models, confirmatory fit index (CFI) $> .95$, root mean square of approximation (RMSEA) $< .05$, and a standardized root mean square residual (SRMR) $< .03$) indicated that each model fit the data well (Kline, 2010). Factor loadings suggested that items loaded sufficiently ($> .40$) onto their respective factors with minimal cross-loadings. All items loaded on the intended factor in the expected direction. Of particular note, as was found in previous research (Patall et al., 2013), the provision of choice items and opportunities for students to work in their own way items loaded on a single factor rather than two separate factors. Among the supportive teacher practice items, there was slight variation across levels in terms of which items loaded onto factors best without excessive cross-loadings. However, items were conceptually interchangeable. Scale scores for each perceived teacher practice and perceived autonomy were calculated by taking the mean of all items loading above .40 on each factor. When factor analyses suggested that a slightly different version of a scale should be used at day versus student levels, we computed multiple

[1] Further details of these analyses are available by request from the first author or at https://motivationlab.wordpress.com/.

versions of the scale to be used at the appropriate level. To assess the internal consistency reliability of each scale on any given day, we computed Cronbach's alpha for each day and took the average across all days. For perceived autonomy, the mean daily alpha was .87. Across the supportive teacher practices, the mean daily alpha was between .73 and .87. Across the thwarting teacher practices, the mean daily alpha was between daily .67 and .82. One scale had a mean alpha slightly below .70 (controlling messages $\alpha = .67$).

Results

Change in perceived practices and autonomy over time

In preliminary analyses, we began by computing variance partition coefficients (VPC; Goldstein, 2011), and intraclass correlation coefficients (Kreft & De Leeuw, 1998) for each perceived teacher practice and students' experience of autonomy in science class to gauge the daily (within-person) variation in each over the course of the 6-week instructional unit compared to the variation in experiences of autonomy and perceptions of practices across students (aggregated across days) and classrooms (aggregated across days and students). VPCs suggested that between 35% and 55% of the variance in perceived teacher practices was at the day level. A similar amount of variance was at the student level (VPCs ranged between 37% and 57%) and limited variability was observed at the classroom level (VPCs ranged between 3% and 17%). Similarly, about 13% of the variation in perceived autonomy in class was between classrooms, 46% was within classrooms between students, and 41% was within students between days. Results suggested that there was a substantial proportion of daily variation in students' perceptions of their teachers' practices and their experience of autonomy over the course of the unit, in addition to a great deal of variation across individual students.

Having established that teachers' practices are perceived to vary from day to day, we next addressed our first research question and examined how experiences of autonomy in class and perceptions of teacher practices changed over an instructional unit. To explore this question, we estimated a series of three-level regression models using the mixed procedure in SPSS 21 in which we included response day to represent time over the course of the unit. Response day was grand-mean centered. To accommodate for missing response data, we used a maximum likelihood estimation procedure with robust estimates of standard errors (REML). Maximum likelihood estimation is a superior approach to treating missing data relative to multiple imputation methods in terms of efficiency and ability to produce unbiased, stable estimates. The amount of missing data varied depending on the particular analysis (samples sizes are reported in all tables illustrating results). Because adjacent residuals in repeated measures data are usually correlated across measurement occasions, we specified an AR(1) correlated error structure.

Results (see Table 1) suggested that the nature of change in perceived teacher practices across the six weeks varied depending on the particular practice. Both the students' perceptions that teachers provided choices and considered their preferences and interests increased over days in the 6-week instructional unit. Perceptions that teachers provided controlling messages, suppressed student expression, and provided uninteresting activities also increased over the 6-week instructional unit. In contrast, students perceived teachers to decrease their provision of rationales, opportunities for questions, and informational—encouraging feedback over the course of the instructional unit. There was no change in perceptions of teachers' consideration for negative affect across the unit. Finally, students' experiences of autonomy during class increased over the course of the six-week instructional unit.

Relations between perceived practices and autonomy

First, we computed correlations among the perceived daily teacher practices to check that all individual perceived practices were modestly correlated in an expected pattern such (perceived supportive practices were positively correlated, thwarting practices were positively correlated, and supportive and thwarting practices were negatively correlated; see Table 2). Ensuring that correlations among perceived practices

Table 1. Fixed effect results for multilevel regressions with time predicting students' experiences in science class.

	Predictor		
		Time	
Outcome	Intercept	*b*(SE)	β
Autonomy	2.83	.008(.003)	.04*
Choice[a]	2.49	.02(.004)	.07***
Interests[a]	2.05	.02(.004)	.07***
Rationales	2.86	− .01(.004)	− .05**
Questions[a]	3.62	− .03(.004)	− .13***
Negative affect	2.60	.007(.004)	.03
Feedback[a]	2.76	− .02(.004)	− .08***
Controlling messages	2.44	.007(.003)	.04[a]
Suppression	1.56	.02(.003)	.12***
Uninteresting activities	1.97	.02(004)	.07***

Notes. Level 1 (daily reports) n = 2,128 to 2,298 reports. The "time" variable reflects the day of reporting across the 6 week instructional unit. b = unstandardized regression coefficient. β = standardized regression coefficient. Standardized estimates were computed using the following formula (Hox, 2010): β = (b*sdx)/sdy. SE = standard error. [a]The day level versionof the scale was used. *$p < .05$, **$p < .01$, ***$p < .001$.

was modest was a necessary step to justify our approach of examining individual perceived practices separately in our subsequent tests of each research question. To provide some initial exploration into our hypotheses about the relationships between perceived practice and autonomy, we also computed correlations between daily practices and daily experiences of autonomy in class (see Table 2). As expected, all practices hypothesized to be supportive of autonomy were positively correlated. Likewise, all the practices hypothesized to be thwarting of autonomy were positively correlated. Of note, correlations among practices were modest, ranging from .13 to .33. As for correlations between supporting and thwarting practices, correlations generally hovered close to zero, ranging from –.18 to .09. All six supportive practices were positively correlated with perceived autonomy. Two thwarting practices (controlling messages and use of uninteresting activities) were negatively correlated with perceived autonomy in class. Taken together, the modest values among perceived practices correlations suggest that the nine teacher practices should be considered separately when investigating daily perceived practice.

Next, to address our second research question regarding the relation between students' perceptions of teacher practices and their experiences of autonomy, we conducted a series of three-level random-intercept-only multilevel regressions. For each multilevel model, at level one (the day level) we included time, one daily teacher practice, and perceived autonomy reported on the previous day. We constructed the time variable by consecutively numbering each class session during the unit starting with zero. We opted to use class session as the time metric, as opposed to calendar days or school days elapsed, given Kim-Spoon & Grimm's (2016) recommendation to consider the dominant reasons for why changes in the outcome might occur for choosing a time metric. In our investigation, the dominant reason student

Table 2. Means, standard deviations, and correlations.

	M	SD	1	2	3	4	5	6	7	8	9	10
1. Choice	2.50	.97	—									
2. Interests	2.07	1.03	.33	—								
3. Rationales	2.88	1.04	.13	.17	—							
4. Questions	3.65	1.06	.18	.13	.22	—						
5. Negative affect	2.60	1.09	.20	.26	.14	.18	—					
6. Feedback	2.78	1.03	.21	.21	.27	.31	.22	—				
7. Controlling messages	2.44	.91	− .05	.04	.09	.06	.003	.06	—			
8. Suppression	1.56	.83	.02	.08	− .03	− .18	.06	− .06	.26	—		
9. Uninteresting activities	1.98	1.07	− .04	− .07	− .01	− .13	.01	− .06	.23	.28	—	
10. Autonomy	2.85	.95	.41	.29	.18	.23	.20	.21	− .07	− .01	− .19	—

Note. n = 2,091 to 2,298 reports. Italicized correlations are not significant. All other correlations are $p < .05$.

motivation and engagement in science class was expected to vary is because of their experiences during science class sessions. The prior day's value for the outcome (perceived autonomy) was entered to control for possible carryover effects from one day to the next (e.g., see Reis et al., 2000 for an example of this strategy). The most recent day of reporting was carried forward for the purposes of lagging. Consequently, data from the first day of recording was not used, since there was no prior day for the first day. Including the prior day's outcome value as a predictor allowed us to model change in perceived autonomy from one daily report to the next as a function of students' perceptions of the teacher practice reported on the same day as the outcome. At level two, that is, the student level, we included the mean of the perceived teacher practice across days for each student. At level three, that is, the classroom level, we included the mean of the perceived teacher practices across days and students within a class. We included four control variables at the student level (level two): student sex (0 = *male*, 1 = female), student ethnicity (0 = *Caucasian or Asian*, 1 = *Black, Hispanic, or other ethnicity*), students' free or reduced price lunch eligibility as a measure of SES (0 = *eligible*, 1 = *not eligible*), and prior achievement as assessed by students' grade in the course during the prior unit. We also included two class level (level three) control variables: whether the class was a biological science versus another science area (e.g., physics, chemistry, engineering, environmental science; 0 = *nonbiological focus*, 1 = *biological focus*), and whether the class was advanced or grade typical (0 = *grade typical*, 1 = *advanced*). This model allowed us to explore the links between perceptions of teacher practice and experiences of autonomy at three levels. Day level (within-student) results allowed us to assess day-to-day variation in student's experience of autonomy as a function of student's perception of daily teacher practice. Student level (between-student) results assessed relations between students' cumulative perceptions of teacher practice and experiences of autonomy aggregated across the 6 weeks by calculating the mean for each participant across the 17 possible class days. Class level (between-class) results assessed the relation between each class's perception of their teacher's practices and experience of autonomy by calculating the mean for each classroom across all students in each class and the 17 possible class days.

To decompose between and within-person effects, day-level (within-student) teacher practice predictors were person-mean centered (around each person's own average score), student-level (between-student) teacher practice predictors were class-mean centered (around the average score for the class), and class-level (between-class) teacher practice predictors were grand mean centered (around the sample mean). Time, student, and classroom characteristic control variables, and the prior day's score were grand-mean centered, because they were simply control variables in these models. Again, we used the mixed procedure in SPSS 21, a maximum likelihood estimation procedure with REML to accommodate for missing response data, and specified an AR(1) correlated error structure. Given that these models included a number of student-level covariates, the 22 participants for whom one or more demographic information items were missing were excluded from these analyses. A separate model was first estimated for each perceived teacher practice alone, and then a model with all practices included simultaneously was estimated. The results of these analyses can be seen in Tables 3, 4, 5 and 6.

In the initial models addressing our second research question, all six teacher practices hypothesized to support autonomy positively predicted students' experiences of autonomy at day, student, and class levels, controlling for time, the six student and class characteristics, and perceived autonomy on the prior day. That is, on days when students perceived teachers to provide choices, activities that considered student interests and preferences, rationales for course activities, opportunities for questions, consideration for students' negative affect, and encouraging, informational feedback, their experience of autonomy during class increased relative to the prior class day. Moreover, individual students and classes of students who perceived more of those practices across days during the instructional unit reported higher cumulative autonomy across classes for the unit. Among perceived practices hypothesized to thwart autonomy, only use of uninteresting activities negatively predicted perceived autonomy in class at all three levels (day, student, and class) controlling for time, the six student and class characteristics, and perceived autonomy on the prior day. Controlling messages negatively predicted students' experience of autonomy in class only at the day level, but not aggregated across time for individual students or across students for classrooms. Surprisingly, suppression of student expression did not predict perceived autonomy at any level.

Table 3. Fixed effect results for multilevel regressions with perceived teacher practice (choice provision, consideration for student interests, and rationale provision) predicting perceived autonomy in separate models.

	Teacher Practice Predictor					
	Choice[a]		Interests[a]		Rationales	
Predictor	*b*(SE)	β	*b*(SE)	β	*b*(SE)	β
Class level						
Intercept	2.87(.04)		2.84(.05)		2.86 (.05)	
$Practice_{mean}$	.81(.10)	.36***	.54(.10)	.29***	.48(.10)	.27***
Class content	.11(.08)	.06	− .02(.11)	− .008	− .09(.10)	− .04
Class type	.005(.08)	.02	.02(.11)	.01	− .03(.08)	− .01
Student level						
$Practice_{mean}$	.71(.06)	.42***	.58(.07)	.38***	.54(.06)	.36***
Sex	− .17(.07)	− .09*	− .19(.09)	− .10*	− .13(.08)	− .07
Ethnicity	.13(.08)	.07	.16(.10)	.08	.05(.09)	.02
Free/reduced lunch	− .12(.08)	− .06	− .19(.10)	− .10	− .02(.10)	− .01
Prior course grade	.002(.002)	.03	.002(.003)	.03	.001(.002)	.02
Day Level						
Practice	.35(.02)	.25***	.27(.02)	.17***	.17(.02)	.11***
Time	− .00(.003)	.00	− .002(.004)	− .008	.004(.004)	.02
Lagged outcome	.09(.02)	.09***	.05 (.02)	.05*	.10(.02)	.10***

Notes. Level 1 (daily reports) n = 1,719 to 1,751 reports. Level 2 (students) n = 196. Level 3 (classes) n = 41. Each teacher practice was examined in a separate model predicting perceived autonomy, along with the lagged outcome, time, and four student characteristics and two class characteristics. The "time" variable reflects the day of reporting across the 6 week instructional unit. The "lagged autonomy" variable reflects the prior day's value for perceived autonomy outcome. All teacher practices were measured at the day level. Student level practice variables were created by computing the mean of the perceived teacher practice across days for each student. Class level practice variables were created by computing the mean of the perceived teacher practices across days and students within a class. To indicate that each of these variables were aggregates, the subscript "mean" was added to the predictor label. For student sex, 0 = male and 1 = female. For ethnicity, 0 = Caucasian or Asian and 1 = Black, Hispanic, or other ethnic minority. For free and reduced price lunch eligible, 0 = not eligible for free/reduced price lunch and 1 = eligible for free/reduced price lunch. For class content, 0 = non-biological science and 1 = biological science. For class type, 0 = grade-typical class and 1 = advanced class. Prior course grade was measured continuously. *b* = unstandardized regression coefficient. β = standardized regression coefficient. Standardized estimates were computed using the following formula (Hox, 2010): $\beta = (b^{*}sdx)/sdy$. Standard deviation values reflected the variability at the given level (not total variability). SE = standard error. [a]The day level version of the scale used at level 1 (day level) and the student level version of the scale was used at levels 2 and 3 (student and class levels). An examination of each model using only the day level version of scales at all levels did not produce any notable differences in the results. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Several other patterns in these findings are worth noting. Namely, the effects of teacher practices generally were stronger at the student and class levels relative to the day level. This suggests that perceptions of good practices do generally accumulate to positively predict students' experience of autonomy over time. Moreover, classes that experienced more of these practices during a unit reported experiencing greater autonomy in class. The reverse pattern was likewise true for use of uninteresting activities—perceptions of this practice also accumulated over time to negatively predict students' perceived autonomy over time and classes that perceived teachers to use uninteresting activities to a greater extent across the unit experienced lower autonomy in class. It is also worth noting that choice provision had the strongest relations with perceived autonomy and thwarts had relatively weaker relations compared to supportive practices.

To provide a more conservative approach to addressing our second research question, next we estimated a model in which the associations of all perceived practices with autonomy were estimated simultaneously, along with time, the lagged outcome, the four student characteristics, and the two class characteristics as control variables. Most perceived practices that had been statistically significant in the initial multilevel regressions continued to significantly predict perceived autonomy at least at the day level. Specifically, on days when students perceived their teachers to provide choices, activities that incorporated student interests and preferences, rationales for course activities, opportunities for questions, and consideration for students' negative affect, their experience of autonomy during class increased relative to the prior class day. On days when students perceived their teachers to use uninteresting activities, their autonomy decreased relative to the prior class day. Moreover, students who perceived more choice

Table 4. Fixed effect results for multilevel regressions with perceived teacher practice (question opportunities, consideration for negative affect, and encouraging, informational feedback) predicting perceived autonomy in separate models.

	Teacher Practice Predictor					
	Questions[a]		Negative affect		Feedback[a]	
Predictor	*b*(SE)	β	*b*(SE)	β	*b*(SE)	β
Class level						
Intercept	2.83(.05)		2.84(.05)		2.85 (.05)	
$\text{Practice}_{\text{mean}}$	.57(.14)	.27***	.49(.09)	.28***	.54(.12)	.27***
Class content	− .06(.11)	− .03	.04(.10)	.02	− .07(.10)	− .03
Class type	− .01(.12)	− .01	.02(.10)	.01	.05(.11)	.03
Student level						
$\text{Practice}_{\text{mean}}$	.53(.07)	.32***	.38(.06)	.27***	.54(.06)	.36***
Sex	− .25(.08)	− .13**	− .27(.09)	− .14**	− .18(.09)	− .09
Ethnicity	.08(.10)	.04	.17(.10)	.09	.06(.10)	.03
Free/reduced lunch	.14(.10)	.07	.007(.11)	.004	− .01(.10)	− .004
Prior course grade	− .004(.002)	− .07	− .002(.003)	− .03	− .002(.002)	− .03
Day Level						
Practice	.20(.02)	.15***	.16(.02)	.11***	.18(.02)	.13***
Time	.01(.004)	.05**	.002(.004)	.009	.008(.004)	.04*
Lagged outcome	.09(.02)	.09***	.09 (.02)	.09***	.09(.02)	.09***

Notes. Level 1 (daily reports) n = 1,716 to 1,855 reports. Level 2 (students) n = 197. Level 3 (classes) n = 41. Each teacher practice was examined in a separate model predicting perceived autonomy, along with the lagged outcome, time, and four student characteristics and two class characteristics. The "time" variable reflects the day of reporting across the 6 week instructional unit. The "lagged autonomy" variable reflects the prior day's value for perceived autonomy outcome. All teacher practices were measured at the day level. Student level practice variables were created by computing the mean of the perceived teacher practice across days for each student. Class level practice variables were created by computing the mean of the perceived teacher practices across days and students within a class. To indicate that each of these variables were aggregates, the subscript "mean" was added to the predictor label. For student sex, 0 = male and 1 = female. For ethnicity, 0 = Caucasian or Asian and 1 = Black, Hispanic, or other ethnic minority. For free and reduced price lunch eligible, 0 = not eligible for free/reduced price lunch and 1 = eligible for free/reduced price lunch. For class content, 0 = non-biological science and 1 = biological science. For class type, 0 = grade-typical class and 1 = advanced class. Prior course grade was measured continuously. *b* = unstandardized regression coefficient. β = standardized regression coefficient. Standardized estimates were computed using the following formula (Hox, 2010): $\beta = (b^*\text{sdx})/\text{sdy}$. Standard deviation values reflected the variability at the given level (not total variability). SE = standard error. [a]The day level version of the scale used at level 1 (day level) and the student level version of the scale was used at levels 2 and 3 (student and class levels). An examination of each model using only the day level version of scales at all levels did not produce any notable differences in the results. $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.

opportunities, rationales, questions, and less use of uninteresting activities across days during the instructional unit reported higher cumulative autonomy for the unit. Classes (of students) who perceived more choice opportunities, greater consideration for negative affect, and less use of uninteresting activities across the instructional unit reported higher aggregated autonomy for the unit. Controlling messages and encouraging, informational feedback no longer predicted perceived autonomy in the simultaneous model. Students' perceptions of teacher provision of choices and use of uninteresting activities were the only variables to predict perceived autonomy at all three levels, positively and negatively, respectively. Choice provision was the strongest predictor at all levels. Results highlight that students' perceptions of six of nine teacher practices (choice, consideration for preferences and interests, rationales, question opportunities, consideration for negative affect, and use of uninteresting activities) make unique contributions to explaining students' experiences of autonomy on any given day, with choice provision[2] being a particularly powerful predictor of autonomy, regardless of level of analysis. In addition, sex and class content predicted experiences of autonomy such that male students and classes studying biological science content felt more autonomous across the six weeks than female students and classes studying non-biological science content (e.g., physics, chemistry, etc.).

[2]To explore the possibility that choice provision is the strongest predictor of perceived autonomy because it overlaps in the conceptualization of the perceived autonomy measure, we reconducted all analyses involving the provision of choice after recomputing perceived autonomy scale, excluding two items that specifically referred to choosing. Coefficients were within .02 of original analyses, suggesting that the redundant conceptualization was not the primary explanation for choice emerging as the strongest predictor of perceived autonomy.

Table 5. Fixed effect results for multilevel regressions with perceived teacher practice (controlling messages, suppression of student perspectives, and use of uninteresting activities) predicting perceived autonomy in separate models.

	Teacher Practice Predictor					
	Controlling messages		Suppression		Uninteresting activities	
Predictor	*b*(SE)	β	*b*(SE)	β	*b*(SE)	β
Class level						
Intercept	2.80(.06)		2.81(.06)		2.83(.05)	
$\text{Practice}_{\text{mean}}$	− .06(.18)	− .02	.07(.19)	.02	− .39(.13)	− .18**
Class content	− .04(.13)	− .02	− .04(.13)	− .02	.04(.11)	.02
Class type	.14(.12)	.08	.16(.12)	.08	.04(.12)	.02
Student level						
$\text{Practice}_{\text{mean}}$	.13(.07)	.08	− .07(.08)	− .04	− .25(.06)	− .19***
Sex	− .24(.09)	− .13*	− .25(.09)	− .13**	− .27(.10)	− .14**
Ethnicity	.07(.11)	.04	.05(.11)	.03	− .01(.11)	− .005
Free/reduced lunch	.08(.11)	.04	.10(.11)	.05	.06(.11)	.03
Prior course grade	.001(.003)	.01	− .0003(.003)	− .01	− .001(.003)	− .02
Day Level						
Practice	− .06(.02)	− .04*	.003(.03)	.002	− .17(.02)	− .12***
Time	.004(.004)	.02	− .002(.004)	.02	.01(.004)	.03
Lagged outcome	.14(.02)	.14***	.16(.02)	.16***	.10(.02)	.10***

Notes. Level 1 (daily reports) n = 1717 to 1,855 reports. Level 2 (students) n = 196 to 197. Level 3 (classes) n = 41. Each teacher practice was examined in a separate model predicting perceived autonomy, along with the lagged outcome, time, and four student characteristics and two class characteristics. The "time" variable reflects the day of reporting across the 6 week instructional unit. The "lagged autonomy" variable reflects the prior day's value for perceived autonomy outcome. All teacher practices were measured at the day level. Student level practice variables were created by computing the mean of the perceived teacher practice across days for each student. Class level practice variables were created by computing the mean of the perceived teacher practices across days and students within a class. To indicate that each of these variables were aggregates, the subscript "mean" was added to the predictor label. For student sex, 0 = male and 1 = female. For ethnicity, 0 = Caucasian or Asian and 1 = Black, Hispanic, or other ethnic minority. For free and reduced price lunch eligible, 0 = not eligible for free/reduced price lunch and 1 = eligible for free/reduced price lunch. For class content, 0 = non-biological science and 1 = biological science. For class type, 0 = grade-typical class and 1 = advanced class. Prior course grade was measured continuously. *b* = unstandardized regression coefficient. β = standardized regression coefficient. Standardized estimates were computed using the following formula (Hox, 2010): $\beta = (b^{*}sdx)/sdy$. Standard deviation values reflected the variability at the given level (not total variability). SE = standard error. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Variation in relations between perceived practices and autonomy across time

To examine the part of our second research question regarding as to whether daily relations between perceived teacher practices and autonomy in class vary over the course of an instructional unit, we estimated a series of three-level random-intercept-only regressions that included the interaction term between each perceived practice and time at the daily level only in separate models. Otherwise, the model for each practice predicting autonomy was identical to those previously described. Significant interactions with time were found for three of nine perceived teacher practice predictors, perceived consideration for negative affect ($B = .01$, SE = .005, $\beta = .04$, $p < .04$), suppression ($B = .02$, SE = .007, $\beta = .06$, $p < .003$), and use of uninteresting activities ($B = .01$, SE = .005, $\beta = .04$, $p = .03$), controlling for the prior day experience of autonomy and the six student and class characteristics. To get a better sense of this interaction, we conducted simple slope analyses that tested the significance of the relation between each practice and autonomy early in the unit at day 3 and later in the unit on day 10. Whereas the coefficient for consideration for negative affect was $\beta = .11$ ($p < .001$) on day 3, it was stronger at day 10 ($\beta = .18$, $p < .001$). That is, interaction results suggested that daily perceptions that teachers considered students' negative affect predicted increases in autonomy more so later in an instructional unit compared to early in the unit. For suppression and use of uninteresting activities, whereas the coefficient for each was negative early in the unit on day 3 ($\beta = -.12$ and $-.22$, $p < .02$ and $.001$), it was null for suppression and weaker for use of uninteresting activities (though still negative) at day 10 ($\beta = .03$ and $-.15$, $p = .35$ and $< .001$). That is, results suggest that daily suppression of student perspectives and use of uninteresting activities predicted decreases in daily autonomy in class, more so early in an instructional unit, compared to later in the unit. No other significant interactions with time were found.

Table 6. Fixed effect results for multilevel regression with all perceived teacher practices predicting perceived autonomy in simultaneous model.

	Class level		Student level		Day Level	
Predictor	*b*(SE)	β	*b*(SE)	β	*b*(SE)	β
Intercept	2.88(.03)					
Choice[a]	.75(.12)	.33***	.54(.08)	.32***	.29(.02)	.21***
Interests[a]	.002(.15)	.001	.03(.09)	.02	.14(.02)	.09***
Rationales	−.06(.12)	−.04	.17(.07)	.12*	.08(.02)	.05***
Questions[a]	−.04(.16)	−.02	.20(.09)	.12*	.06(.02)	.05**
Negative affect	.23(.11)	.13*	.07(.05)	.05	.05(.02)	.03*
Feedback[a]	−.05(.16)	−.03	−.08(.08)	−.06	.04(.02)	.03
Controlling messages	−.003(.14)	−.001	.06(.07)	.04	−.02(.02)	−.02
Suppression	−.01(.22)	−.003	.15(.09)	.09	−.01(.03)	−.01
Uninteresting activities	−.40(.15)	−.19*	−.30(.06)	−.23***	−.13(.02)	−.09***
Class content	.18(.08)	.09*				
Class type	−.10(.07)	−.05				
Sex			−.19(.06)	−.10**		
Ethnicity			.04(.08)	.02		
Free/reduced lunch			−.15(.08)	−.08		
Prior course grade			.00(.002)	.00		
Time					.002(.003)	.01
Lagged autonomy					.02(.02)	.02

Notes. Level 1 (daily reports) n = 1,652 reports. Level 2 (students) n = 196. Level 3 (classes) n = 41. The "time" variable reflects the day of reporting across the 6 week instructional unit. The "lagged autonomy" variable reflects the prior day's value for perceived autonomy outcome. For student sex, 0 = male and 1 = female. For ethnicity, 0 = Caucasian or Asian and 1 = Black, Hispanic, or other ethnic minority. For free and reduced price lunch eligible, 0 = not eligible for free/reduced price lunch and 1 = eligible for free/reduced price lunch. For class content, 0 = non-biological science and 1 = biological science. For class type, 0 = grade-typical class and 1 = advanced class. Prior course grade for the prior unit. Student level practice variables were created by computing the mean of the perceived teacher practice across days for each student. Class level practice variables were created by computing the mean of the perceived teacher practices across days and students within a class. *b* = unstandardized regression coefficient. β = standardized regression coefficient. Standardized estimates were computed using the following formula (Hox, 2010): $\beta = (b^{*}sdx)/sdy$. Standard deviation values reflected the variability at the given level (not total variability). SE = standard error. [a]The day level version of the scale used at level 1 (day level) and the student level version of the scale was used at levels 2 and 3 (student and class levels). An examination of each model using only the day level version of scales at all levels did not produce any notable differences in the results. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Variation in relations between perceived practices and autonomy across individuals and classrooms

In exploratory analyses to address our third research question, we examined whether student and classroom characteristics (sex, ethnicity, free or reduced-price lunch eligibility, prior course grade, class content, and class type) might moderate the relations between perceived teacher practices and autonomy in a series of three-level regressions that added interactions between each daily perceived teacher practice, the student-level mean of each perceived teacher practice, or the class-mean of each perceived teacher practice with each of the aforementioned student or classroom characteristics variables. For these models, we specified random intercepts and random slopes for perceived teacher practices across individuals and classes. To simplify each model, we examined each teacher practice and interactions involving each student or class characteristic in separate models. When examining the role of student characteristics as moderators of the relation between a perceived teacher practice and autonomy in class, we specified interactions between the student characteristic and the perceived teacher practice at both the day and student levels. When examining the role of classroom characteristics as moderators of the relation between perceived teacher practices and autonomy, we specified interactions between the class characteristic and each perceived teacher practice at all three levels of analysis. Otherwise, models were identical to those previously described examining the main effects of daily, student mean, and class mean teacher practices on autonomy, controlling for time, the prior day's outcome value, and the six student and classroom characteristics.

Significant interactions with sex were found for three of nine perceived teacher practice predictors. The interaction between students' cumulative perception of teachers' consideration for student interests and sex ($B = .31$, SE $= .14$, $\beta = .15$, $p < .03$) indicated that the positive link between perceived consideration for students' interests and preferences and their cumulative experience of autonomy across the unit was greater for female students compared to male students. Simple slope analyses suggested that, whereas the coefficient for the relation between the student mean of perceived consideration for student interests and perceived autonomy in class was $\beta = .47$ ($p < .001$) for female students, the coefficient was $\beta = .27$ ($p = .001$) for male students. In contrast, thwarting practices seemed to be particularly detrimental for male students. Significant interactions between sex with students' cumulative perception of teachers' suppression of student perspectives ($B = .40$, SE $= .18$, $\beta = .17$, $p < .03$) and use of uninteresting activities ($B = .27$, SE $= .14$, $\beta = .16$, $p = .05$) indicated that the negative link between suppression or use of uninteresting activities and cumulative perceived autonomy across the unit was apparent only for male students ($\beta = -.16$ and $-.31$; $p = .03$ and $< .001$), but not female students ($\beta = .08$ and $-.10$; $p = .30$ and $.12$).

Significant interactions with free or reduced-price lunch eligibility were found for perceived provision of rationales and controlling messages. The interaction between daily perceived provision of rationales and free or reduced-price lunch eligibility ($B = .12$, SE $= .05$, $\beta = .05$, $p < .03$) indicated that the increase in daily perceived autonomy in class as a function of perceived rationale provision was greater for students who were eligible for free and reduced price lunch ($\beta = .15$, $p < .001$) compared to those who were not eligible ($\beta = .08$, $p < .001$). The interaction between students' cumulative perception of teachers' controlling messages and free or reduced-price lunch eligibility ($B = .31$, SE $= .14$, $\beta = .15$, $p < .03$) indicated that the controlling messages were positively associated with the cumulative experience of autonomy in class for students who were eligible for free or reduced price lunch ($\beta = .25$, $p < .003$), but not for students who were ineligible ($\beta = -.02$, $p = .81$).

Significant interactions with students' prior course grade were found for perceived provision of rationales and suppression of student perspectives. A significant interaction between daily perceived provision of rationales and prior course grade ($B = -.004$, SE $= .001$, $\beta = -.05$, $p < .003$) indicated that the increase in perceived autonomy in class as a function of perceived rationale provision was greater for students who had lower than average prior course grades (simple slope at 1 *SD* below mean course grade: $\beta = .15$, $p < .001$) compared to those who had higher than average prior course grades (simple slope at 1 *SD* above mean course grade: $\beta = .06$, $p < .008$). A significant interaction between students' cumulative perception of teachers' suppression and prior course grade ($B = .008$, SE $= .004$, $\beta = .10$, $p < .04$) indicated that the suppression had a negative association with cumulative perceived autonomy for students with low prior course grades (simple slope at 1 and 2 *SD* above mean: $\beta = -.10$ and $-.18$, $p = .08$ and $< .03$), but not for students with high prior course grades (simple slope at 1 and 2 *SD* above mean: $\beta = .05$ and $.13$, $p = .42$ and $.17$).

Significant interactions with class type (grade typical or advanced) were found for four of nine perceived teacher practice predictors. Significant interactions between class type with students' cumulative perception of teachers' consideration for students' negative affect and provision of encouraging, information feedback ($B = -.38$ and $-.32$, SE $= .14$ and $.13$, $\beta = -.21$ and $-.15$, $p < .02$) indicated that the positive links between cumulative perceived autonomy across the unit with perceived consideration for negative affect and feedback were greater for students in grade-typical classes ($\beta = .44$ and $.47$, $p < .001$) compared to advanced classes ($\beta = .17$ and $.25$, $p = .02$ and $< .001$). In contrast, the interaction between the class perception of question opportunities and class type ($B = .59$, SE $= .27$, $\beta = .20$, $p < .04$) indicated that the positive association between perceived question opportunities and the experience of autonomy was greater in advanced classes ($\beta = .42$, $p < .001$), compared to grade-typical classes ($\beta = .14$, $p = .12$). Likewise, the interaction between the class perception of teachers' use of uninteresting activities and class type ($B = -.56$, SE $= .26$, $\beta = -.16$, $p = .04$) indicated that the negative link between perceived use of uninteresting activities and the experience of autonomy was greater in advanced classes ($\beta = -.36$, $p < .001$) compared to grade-typical classes ($\beta = -.10$, $p = .18$). No interactions were found involving ethnicity or class content.

Taken together, interactions suggested that a number of perceived practices, particularly those hypothesized to be supportive, had the strongest links with experiences of autonomy for those students traditionally less engaged in science or most at risk of failing (e.g., girls, lower-SES students, lower achievers, and students in grade-typical classes), and thwarting practices appeared more likely to be negatively linked with experiences of autonomy for students traditionally most engaged in science (e.g., boys, higher-SES students, high achievers, and students in advanced courses).

Interactions between perceived practices

Finally, to address our fourth research question and assess our hypotheses that perceptions of autonomy-supportive practices bolster the positive effects of each other and likewise, perceptions of autonomy-thwarting practice strengthen the negative effects of each other, we estimated a series of three-level random-intercept-only regressions that included interaction terms between perceived practices at each level. These models were similar to those previously described, except that these models each included only two practices and their interaction at each level, along with the time and lagged outcome covariates, but not student and class characteristics covariates so as to avoid excluding data from individuals for whom demographics were not made available. When higher level interaction terms were not statistically significant, the nonsignificant interaction was removed from the model. Variables were centered as previously described.

Results (see Table 7) provided support for our hypothesis that supportive practices bolster the effects of each other. Seven of 15 possible interactions (47%) among the six supportive practices were statistically significant at the day level. Significant day-level interactions were found for choice provisions with consideration for student preferences and interests and opportunities to express negative affect. Daily perceived rationales for importance interacted with daily perceived question opportunities and daily question opportunities interacted with daily consideration for students' preferences and interests. Daily perceived opportunities to express negative affect interacted with daily perceived informational-encouraging feedback and consideration for students' preferences and interests. Finally, daily perceived informational-encouraging feedback interacted with daily perceived consideration for students' preferences and interests. As for interactions at other levels, the interaction between perceived opportunities to express negative affect and informational-encouraging feedback was also significant at the student level. With one exception, all interactions between perceived supportive practices suggested that the benefits of one supportive practice for perceived autonomy were enhanced when the other was high rather than low. The one exception to this pattern was the interaction between perceived opportunities to express negative affect and information/encouraging feedback at the day level. This interaction suggested that the relation between daily perceived opportunities to express negative affect and perceived autonomy was greater when daily perceived feedback was low. Likewise, the relation between daily perceived feedback and perceived autonomy was greater when daily perceived opportunities to express negative affect was low.

We also found that thwarting practices interacted at the day level (see Table 7). Significant interactions were found for two of three (67%) day-level interactions. Specifically, a significant interaction was found between daily perceived controlling messages and uninteresting activities, as well as between daily perceived suppression and uninteresting activities ($B = .12$, SE $= .03$, $\beta = .06$, $p < .001$), but not between controlling messages and suppression. These interactions suggested that the negative relations between perceptions of daily controlling messages and suppression with perceived autonomy were minimized or even positive (in the case of suppression) when the students perceived that teachers were providing uninteresting activities.

Finally, 15 of 18 possible interactions (83%) between the three thwarting practices and each of the six supportive practices were statistically significant at the day level (see Table 7). Specifically, daily perceived controlling messages interacted with daily perceived choice, consideration for student preferences and interests, rationales, question opportunities, opportunities to express negative affect, and feedback. Daily perceived suppression interacted with daily perceived choice, rationales, opportunities to express negative affect, and feedback. And, finally, daily perceived use of uninteresting activities interacted with

Table 7. Summary of statistically significant interactions from multilevel regressions examining interactions among perceived teacher practices predicting perceived autonomy.

Interaction	Intercept *b*(SE)	Student-level *b*(SE)	Student-level *β*	Day-level *b*(SE)	Day-level *β*
Interactions among supports					
Choice[a] x Interests[a]	2.86(.06)	—	—	.06(.003)	.03*
Choice[a] x Negative affect	2.86(.06)	—	—	.07(.03)	.04*
Interests[a] x Questions	2.85(.06)	—	—	.08(.03)	.04**
Interests[a] x Negative affect	2.86(.06)	—	—	.05(.03)	.03*
Interests[a] x Feedback	2.86(.06)	—	—	.08(.03)	.04**
Rationales x Questions[a]	2.86(.06)	—	—	.10(.03)	.05***
Negative affect x Feedback[a]	2.83(.06)	.15(.07)	.08*	−.07(.03)	−.04*
Interactions among thwarts					
Controlling messages x Uninteresting activities	2.86(.06)	—	—	.08(.03)	.04**
Suppression x Uninteresting activities	2.86(.06)	—	—	.12(.03)	.06***
Interactions between supports and thwarts					
Choice[a] x Controlling messages	2.87(.06)	—	—	.07(.03)	.04**
Choice[a] x Suppression	2.86(.06)	—	—	.12(.03)	.05***
Choice[a] x Uninteresting activities	2.87(.06)	—	—	.06(.03)	.03*
Interests[a] x Controlling messages	2.86(.06)	—	—	.09(.03)	.04**
Rationales x Controlling messages	2.85(.05)	.19(.08)	.09*	.14(.04)	.06***
Rationales x Suppression	2.87(.06)	—	—	.17(.04)	.06***
Rationales x Uninteresting activities	2.88(.06)	—	—	.07(.03)	.03*
Questions[a] x Controlling messages	2.84(.06)	—	—	.05(.03)	.03*
Questions[a] x Uninteresting activities	2.87(.06)	—	—	.09(.02)	.05***
Negative affect x Controlling messages	2.86(.06)	—	—	.07(.03)	.04*
Negative affect x Suppression	2.86(.06)	—	—	.07(.03)	.04*
Negative affect x Uninteresting activities	2.87(.06)	—	—	.07(.03)	.04*
Feedback[a] x Controlling messages	2.85(.06)	.17(.08)	.08*	.17(.03)	.08***
Feedback[a] x Suppression	2.88(.06)	—	—	.15(.03)	.06***
Feedback[a] x Uninteresting activities	2.88(.06)	—	—	.08(.03)	.04**

Notes. Level 1 (daily reports) n = 2,091 to 2,298 reports. Level 2 (students) n = 218. Level 3 (classes) n = 43. Fixed interaction effects presented only for models in which a significant interaction was found. For all models, time and lagged autonomy was included as covariates. Upper level variables and interactions were excluded when not significant. There were no interactions between teacher practice variables at the class level. *b* = unstandardized regression coefficient. *β* = standardized regression coefficient. Standardized estimates were computed using the following formula (Hox, 2010): $\beta = (b^{*}sdx)/sdy$. Standard deviation values reflected the variability at the given level (not total variability). SE = standard error. [a]The day level version of the scale used at level 1 and the student level version of the scale was used at level 2. An examination of each model using only the day level version of scales at all levels did not produce any notable differences in the results.. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

daily perceived choice, rationales, question opportunities, opportunities to express negative affect, and feedback. The interactions between perceptions of controlling messages with rationales and feedback were also significant at the student level.

In all cases, interactions suggested a contrast effect in which high levels of perceived thwarting practices magnified the positive relation between perceived supportive practices and perceived autonomy, and likewise, high levels of perceived supportive practices minimized the negative relation between perceived thwarting practices and perceived autonomy.[3]

Discussion

This investigation examined the role of various perceived teaching strategies in students' daily and cumulative experience of autonomy in high school science classes. We focused on a set of nine practices routinely identified by motivation researchers to be relevant to the experience of autonomy and used a diary

[3]A detailed description of simple slope analyses decomposing all interactions between pairs of practices are available by request or at https://motivationlab.wordpress.com/.

method to track daily fluctuations in students' perceptions of those practices and experiences of autonomy during science class over a 6-week instructional unit. This investigation was unique in that the design allowed us to explore change in students' perceptions of their teachers' practice over time and compare relations for the individual components of autonomy-relevant teaching both on a given day and cumulatively over time for an individual student and for a class (of students) within the context of an authentic classroom environment. Thus, all in all, we sought to (a) explore how autonomy-relevant practices and experiences of autonomy may change over the course of an instructional unit, (b) examine the relations between teaching strategies routinely identified as autonomy-relevant with high school science students' daily and cumulative experience of autonomy and explore whether these relations change during the course of an instructional unit, (c) explore whether daily and cumulative relations between perceived practice and experiences of autonomy vary depending on student and classroom characteristics, and (d) examine how the individual perceived practices interact in their relations with science students' daily and cumulative experiences of autonomy.

In line with previous theory and research (e.g., Assor et al., 2002; Reeve & Jang, 2006; Patall et al., 2013), results suggested that students' perceptions of 7 out of 9 teacher practices predicted students' experience of autonomy both daily, as well as cumulatively over time. Indeed, students' perceptions that their teachers provided choices, considered their preferences and interests during class activities, provided rationales for why course activities were important, gave students opportunities to express negative feelings about what was happening in class, allowed time for student questions, gave feedback that was informative or encouraging, and refrained from requiring uninteresting activities all predicted enhanced experiences of autonomy on any given day, as well as across the 6 weeks for students and for classrooms as a whole. Further, these perceived practices generally had stronger positive (or negative in the case of use of uninteresting activities) relations with experiences of autonomy at student and class levels, suggesting that the small effects of practices on any given day do accumulate over time to influence students' cumulative experience of autonomy in a class. We were surprised to find that students' perceptions that their teachers suppressed student perspectives did not have a statistically significant negative effect on experiences of autonomy. Nonetheless, these curious findings were explained once we explored the interactions between perceived teacher practices and between practices and student or classroom characteristics (discussed in the following) and found that the relation between thwarting practices and experiences of autonomy varied a great deal depending on the level of other teacher practices and a number of student and classroom characteristics.

When all practices were included in the model, each perceived supportive practice, except for feedback, remained statistically significant at the day level, as did the negative effect of perceiving the teacher to require uninteresting activities. Relatively fewer practices remained statistically significant when the associations of all practices were estimated simultaneously at the student and teacher levels. Specifically, provision of choice, rationales, questions, and use of uninteresting activities emerged as the strongest predictors of autonomy at the student level. Choice provision, consideration for students' negative affect, and use of uninteresting activities emerged as the strongest predictors of autonomy at the class level. Importantly, day-level analyses indicated that students' perceptions of teachers' practices predicted their experience of autonomy that day over and above the experience of autonomy on the previous day. In fact, for most practices, the power of the perceived practice to predict the day's experience of autonomy was approximately equal to, or greater than, that of the students' experience of autonomy in the past, implying that daily fluctuations in perceptions of teacher practice play an equal or greater role in students' in-class experience of autonomy as students' habitual motivational tendencies.

Along these lines, a few patterns in the results are particularly worth noting. Namely, although most of the perceived practices seem to play a small role in supporting students' experiences of autonomy, perceptions of having choices emerged as the strongest positive predictor of feeling autonomous at every level of analysis, with the negative effect of perceived use of uninteresting activities being a close second, when the impacts of the nine practices were estimated simultaneously. The utility of choice provision as a key autonomy-supportive practice, and the extent to which it ubiquitously supports motivation across people and circumstances has been questioned recently (e.g., Assor et al., 2002; Reeve, Nix & Hamm, 2003, Patall et al., 2013; 2014). We concur that conditions in which choice provision fails to support

motivation certainly exist. However, we argue that this finding is not surprising, in that feeling that one has a choice in one's behavior is at the heart of the definition of autonomy. As such, it should come as no surprise that when feelings of autonomy are directly assessed as the outcome of focus, choice provision would emerge as a strong, if not the strongest, predictor (e.g., Patall et al., 2013). Part of the power of providing choice may come from the fact that it is a concrete practice that actively involves the recipient, making it easily recognized by recipients and observers alike and a particularly salient influence on the experience of autonomy when it does occur.

A provocative pattern to emerge from this investigation was that across a variety of supportive practice pairs, the relation between one perceived supportive practice and students' experiences of autonomy on a given day was enhanced when the perception of a second supportive daily practice was also high. In fact, we found this same interaction pattern for six pairs of supportive practices at the day level and one more pair at the student level. Several clusters of supportive practices that interacted emerged. Choice, considerations for student interests, and consideration for negative affect was one cluster of supportive practices that all interacted and bolstered the effects of one another. Opportunities for questions also seemed to interact with both consideration for student preferences or interests and the provision of rationales. Thus, in line with our expectations and self-determination theory, it would seem that the positive effects of some supportive practices are enhanced when a second is also high. Finally, information and encouraging feedback bolstered the effects of both consideration for student preferences or interests and consideration for students' negative affect, though the bolstering effect was only found at the student level for the latter.

In contrast to our predictions, we did not find that the negative effects of any one controlling practice to be heightened when a second controlling practice was also high. Rather, it seemed that the negative effects of controlling practices, like controlling messages and explicit suppression of student expression, were mitigated in the presence of the student perceiving the teacher to be providing uninteresting activities. Though this was not our prediction, it makes sense. The functional significance of these practices differs depending on the nature of the activity students are being asked to engage in. In the context of an uninteresting task, a teacher using controlling messages and suppressing students' thoughts and opinions may appear justified or necessary to students, rather than intentionally controlling. However, in the context of neutral or interesting tasks, controlling messages and suppression may then be perceived as intentional and excessive attempts by the teacher to control students' behavior.

We found it particularly encouraging to discover a contrast-dampening pattern of interaction between supporting and thwarting teacher practices in which the presence of a perceived thwart heightened the positive effects of perceived supports, but the presence of a perceived support dampened negative effects of perceived thwarts for 15 support-thwart pairs. Such a pattern represents the most optimistic possibilities for teacher practice. That is, it seems inevitable that on occasion even teachers striving to be autonomy-supportive will either intentionally or inadvertently use a controlling strategy to gain compliance from students. Our findings suggest that when this happens, simultaneous or subsequent use of autonomy-supportive practices may mitigate any negative effects of that practice on students' feelings of autonomy, and in fact, the autonomy-supportive practice may gain more power to support students' autonomy when contrasted with controlling practices.

Interactions among the practices were not the only way we found the effects of perceived teacher practices to vary. We also found the relationship between practices and experiences of autonomy to vary depending on a number of characteristics of the student and the classroom. We found five instances in which perceived supportive practices were linked more strongly with experiences of autonomy for individuals traditionally less engaged in science or more at risk of failure relative to counterparts not traditionally disadvantaged in science. Specifically, more so than male students, female students perceiving their teachers to work students' interests and preferences into activities across the unit reported experiencing greater cumulative autonomy. Students qualifying for free or reduced-price lunch and those who had a low prior unit grade in the science course experienced a greater increase in autonomy on days in which teachers provided rationales for why work may be important or useful relative to non-eligible and higher achieving counterparts. More so than students in advanced classes, students in grade-typical science courses perceiving their teachers to be considerate of their negative affect toward course activities

and to provide feedback that was encouraging and informative across the unit reported experiencing greater cumulative autonomy. There was only one instance in which a perceived thwarting practice was negatively related with autonomy more strongly for traditionally less engaged or more at risk students—that is, more so than for students with a high prior course grade, students with low prior course grades perceiving their teachers to suppress student perspectives across the unit reported experiencing lower cumulative autonomy. In contrast, students traditionally engaged in science were more likely to experience lower autonomy in association with thwarting teacher practices. Specifically, more so than female students, male students perceiving their teachers to suppress student perspectives and rely on uninteresting and meaningless activities across the unit reported experiencing lower cumulative autonomy. More so than for grade-typical science classes, advanced science classes perceiving their teachers to rely on uninteresting and meaningless activities across the unit reported experiencing lower cumulative autonomy. There was only one instance in which a perceived supportive practice was related with autonomy more strongly for students traditionally engaged in science. That is, more so than for grade-typical science classes, advanced science classes perceiving their teachers to provide opportunities for questions across the unit reported experiencing higher cumulative autonomy. As a whole, this pattern of results suggests that teaching practices supportive of autonomy may play a particularly important role in supporting the motivation of students traditionally less engaged or at risk of failure in science coursework (e.g., girls, lower SES, lower achievers, and grade-typical classes), while thwarting practices may be particularly detrimental to students who have traditionally been most engaged in science domains (e.g., boys, higher SES, higher achievers, and advanced classes). It is also worth noting that we did not find any interactions between perceived practices and the particular content of science courses, suggesting that these motivational practices are likely to be equally effective across most domains of science.

Finally, the brief intensive diary design of our study afforded us the opportunity to explore change in teacher practices as perceived by students and the relations between perceived practices and student autonomy across an instructional unit. Results suggested that the nature of change varied depending on the particular practice. Namely, the provision of choice and consideration for student preferences and interests increased over instructional units. In line with this pattern, students also reported increased feelings of autonomy over the course of the instructional unit. The provision of rationales regarding importance, question opportunities, and information and encouraging feedback all declined across the unit. Unfortunately, students also perceived that teachers' controlling practices increased across the instructional unit. The salience of choice in autonomy support is reiterated, given the increase in autonomy despite declines in perceptions of some supportive practices and increases in perceptions of thwarting practices.

We can only speculate on the reasons that students perceive their teachers to change in their use of various strategies through the course of an instructional unit. Teachers may believe it to be effective to establish rules for the class or engage in some standard activities before allowing students many choices or opportunities for incorporating their personal preferences and interests. Teachers may find that there is a greater need for rationales about how course topics and activities are going to be useful or important toward the beginning of a unit, when students have limited exposure regarding what is to come. Likewise, greater question opportunities and informational or encouraging feedback may be needed during the earlier stages of students' learning in an instructional unit. Finally, though we hope that autonomy-thwarting strategies would be kept to a minimum throughout an instructional unit, we speculate that teachers feel greater pressure themselves to accomplish instructional goals as district-mandated instructional units come to a close. As such, students may perceive teachers to impose more controlling strategies, presumably in an effort on the part of the teacher to complete required or self-determined goals for instruction during that unit.

These changes in the perceived use of practices were also accompanied by changes in the nature of their relations with students' experience of autonomy across the unit for three of the practices. Perceived suppression of student perspectives and use of uninteresting activities had a stronger negative effect on daily autonomy later, relative to early, in the unit. Likewise, perceived consideration for students' negative affect had a stronger positive effect on daily autonomy later in the unit. We suspect that these patterns may reflect, in part, teacher and student expectations about when some practices are most effective and the

likelihood that autonomy-relevant practices change meaning as the external consequences of mastering the material inevitably become more salient (i.e., as exam time approaches at the end of the unit). That is, suppression of student perspectives and use of uninteresting activities may come to be expected as a necessary strategy as test time approaches, weakening their functional significance for students' experiences of autonomy. Teachers' consideration for students' negative affect may have a stronger effect on students' daily experiences of autonomy toward the end of the unit as exam time approaches and students emotions about the extent to which material has been mastered are heightened.

Implications for practice

There would seem to be a number of possible implications for science teaching, and likely teaching in general, given that we found no interactions between class content and perceived teacher practices. Past research has routinely shown that students' experience of autonomy is related to an array of adaptive motivation and learning outcomes (e.g., Reeve & Jang, 2006; Jang, Kim, & Reeve, 2012; Patall, Dent, Oyer & Wynn, 2013). As such, teachers hoping to support students' motivation and learning via their experience of autonomy may find it particularly useful to emphasize students' choices in the classroom and minimize their use of uninteresting and meaningless activities (e.g., busywork). Although most other perceived practices examined also had small daily effects on autonomy, students' perceptions of choices and use of uninteresting activities had the largest and most consistent effects at day, student, and class levels once all other practices were considered. Moreover, among significant interactions involving these two practices, few changed the direction of their effects, suggesting that choice and uninteresting activities may have a more uniform effect across students and contexts than other practices.

With that basic recommendation in mind, our results also suggested that teachers should use a constellation of supportive practices on any given day because we found that the effects of some perceived supportive practices for the days' experience of autonomy were bolstered when others were also high. Thus, while providing choices is a good strategy to heighten a student's experience of autonomy on any given day, pairing this strategy with others (for example, activities that reflect student interests and preferences) is likely to yield even greater benefits. By the same token, teachers should feel reassured that the occasional controlling practice will not have undue negative effects on students' experience of autonomy. Though we would not recommend that teachers intentionally attempt to be controlling, our results suggested that the detrimental effects of students perceiving controlling practices on autonomy emerge particularly at the beginning of the unit and when autonomy-supportive practices are absent. Thus, though additional research is needed to replicate our findings, our results suggest that teachers should take care to also provide autonomy-supportive practices in those situations when controlling practices are unavoidable. Doing so appears to mitigate the negative effects of controlling practices and likewise, supportive practices may get an added boost for enhancing the experience of autonomy when contrasted with controlling practices.

Finally, our exploration of interactions involving teacher practices and student and classroom characteristics suggested that practices may differentially benefit or disadvantage certain students and, thus, could be used strategically by teachers depending on the populations they serve or contexts within which they teach. For teachers who find themselves serving populations of students who have not traditionally been strongly engaged in science (e.g., girls, low SES, low achievers, and grade-typical students), providing autonomy support that focuses on directly relaying encouraging information and catering to students existing interests seems critical. In particular, teachers who serve such students are likely to find that relying on interesting activities, providing rationales, giving plenty of encouraging, informational feedback, and being considerate of students' negative affect (particularly toward the end of the unit as test time approaches) are approaches that will support their students' experience of autonomy. In contrast, teachers may want to take particular care to avoid strategies known to thwart autonomy (for example, suppression and use of uninteresting activities) if they primarily serve a population of students who have traditionally been engaged in science domains (e.g., males, higher SES, higher achievers, advanced classes).

Limitations and directions for future research

Given the potential practical implications of understanding the links between teachers' practices and students' experiences of autonomy, as well as subsequent motivation and achievement, it would seem imperative that future research replicate and extend the findings of our investigation. One limitation of this research is the reliance on student self-report. Relying exclusively on students' self-reports leaves open the possibility that response-bias and shared-method variance may be influencing the results. Although there are examples of researchers using observation to determine teachers' autonomy supporting or thwarting practice (e.g., De Meyer et al., 2014; Reeve et al., 2004), we know of no research in which individual components of autonomy-relevant practice were observed as separate coding categories and used as separate variables to predict outcomes. We believe that a nuanced understanding of what makes for optimal autonomy-supportive teaching practice over time and contexts requires detailed coding at the individual teacher strategy level.

Although one of the strengths of our investigation is the intensive longitudinal design that allowed us to control for prior levels of the outcome variable to model change from one day to the next, such a design should not be taken to imply causation. As such, it is imperative that future research use experimental designs in authentic classroom contexts that isolate the effects of autonomy-relevant practices, especially given the complex set of results that emerged regarding how individual practices interact with each other and students or classroom characteristics. Moreover, future research focused on autonomy-relevant teaching practice should more routinely attend to the role of student and classroom characteristics, given that this study highlighted a number of interactions involving such characteristics.

Our findings regarding change in perceived autonomy-relevant practices over the 6 weeks, and their relations with student autonomy, suggest that they each may serve a different function at various stages or contexts for learning. Beyond exploring change over time, future research might consider exploring whether each practice is equally effective at various phases of learning across time (e.g., Fitts & Posner, 1967; Zimmerman, 2000). Such questions might be best addressed in intensive longitudinal designs that better monitor the nature of the learning activities and the learning stage to uncover variability in the effects of practices for supporting autonomy and motivation. Along these same lines, analysis of moment-by-moment interactions may allow for more confident conclusions about the direction of the relations and may provide an opportunity to better understand the complex interactions among practices.

Conclusions

This investigation adds to the growing body of research exploring the nature of autonomy-relevant teaching and the relations of its individual components with adolescent students' experiences of autonomy. Given the established value of feeling autonomous among adolescent students, we believe the effort to continue to gain a nuanced understanding of autonomy-supportive and -thwarting practices remains an important goal of motivation science, education, and psychology. Understanding the complexity involved in supporting adolescents' autonomy in the classroom will allow for the development of more effective interventions and improved recommendations for practitioners.

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