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Fernando Núñez-Regueiro, Jacques Juhel, Ming-Te Wang. Does need satisfaction reflect positive needs-supplies fit or misfit? A new look at autonomy-supportive contexts using cubic response surface analysis. *Social Psychology of Education*, 2025, 28 (1), pp.43. 10.1007/s11218-024-09959-3 . hal-04920232v2

**HAL Id: hal-04920232**

**<https://hal.science/hal-04920232v2>**

Submitted on 10 Mar 2026

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# Does need satisfaction reflect positive needs-supplies fit or misfit? A new look at autonomy-supportive contexts using cubic response surface analysis

Fernando Núñez-Regueiro<sup>1</sup> · Jacques Juhel<sup>2</sup> · Ming-Te Wang<sup>3</sup>

Received: 5 April 2024 / Accepted: 26 November 2024  
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## Abstract

According to self-determination theory (SDT), teachers' autonomy-supportive behavior fosters students' autonomy and competence needs. However, individual differences in students' needs for autonomy support have been overlooked. Specifically, it is unclear whether variations in students' needs influence how effectively a teacher's support contributes to need satisfaction, and whether matching or exceeding the students' needs is most beneficial. This study addresses these gaps by extending SDT in two ways. Theoretically, it introduces a phenomenology of needs-supplies fit, where need satisfaction depends on the interplay between students' needs for autonomy support and teacher supplies. Methodologically, it introduces cubic response surface analysis (RSA) to model this fit. We tested these extensions using cross-sectional data from 389 French secondary school students ( $M(\text{age})=14.3$  years, grades 6 through 12, 58% female), who self-reported their need satisfaction (autonomy and competence) and supplies and needs in teacher autonomy support. Results from cubic RSA highlighted asymmetric processes, which were overlooked by simpler methods (e.g., quadratic RSA). Matching levels of teacher supplies and student needs positively related to need satisfaction, but this relation reversed at low and high levels of fit. Additionally, misfit effects were asymmetrical: while moderate misfit had minimal impact, extreme excess supplies was related to high satisfaction, whereas extreme deficient supplies to low satisfaction. Overall, supplies exceeding students' needs appeared more beneficial than those merely matching them, but this depended on need levels. These findings underscore the importance of tailoring autonomy-supportive behaviors to individual students' needs, as this can enhance or diminish the beneficial impact of such support.

## Educational relevance and implications statement

Self-determination theory (SDT) contends that teacher autonomy support fosters students' needs for competence and autonomy, thereby enhancing their learning

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Part of this research was presented at the Journées Internationales de Psychologie Différentielle (Núñez-Regueiro & Juhel, 2024b) and at the International Conference on Motivation and Emotion (EARLI SIG8; Núñez-Regueiro et al., 2024b).

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Extended author information available on the last page of the article

processes. This study proposes that students actually differ in how much support they need. To address this, it extends SDT with a conceptual framework for understanding individual differences in psychological needs and introduces new methods for analyzing needs-supplies fit, specifically cubic response surface analysis (RSA). The study provides empirical evidence showing that the effectiveness of teacher autonomy support on need satisfaction largely depends on students' specific need levels. These findings have implications for designing needs. Supportive educational contexts and practices that foster self-determined behavior in schools, while also underscoring the value of cubic RSA over simpler methods (quadratic RSA).

**Keywords** Need satisfaction · Autonomy-supportive contexts · Self-determination theory · Needs-supplies fit · Cubic response surface analysis

## 1 Introduction

A central tenet of self-determination theory (SDT; Deci & Ryan, 1985; Ryan & Deci, 2017) is that human beings grow and thrive in their lives when their psychological needs for relatedness (feelings of belongingness and connection to others), competence (feelings of mastery and success in action), and autonomy (feelings of initiative and ownership of one's action) are satisfied. In the school context, need satisfaction is achieved when teachers provide high-quality support, fostering feelings of relatedness, competence, and autonomy. This positive environment, in turn, enhances students' school engagement, learning, and overall well-being (Chen et al., 2015; Jang et al., 2016; León et al., 2015). A major endeavor of SDT studies is therefore dedicated to revealing which teaching behaviors in the class (e.g., autonomy-supportive behavior) provide optimal support to student motivation (Reeve et al., 1999; Ryan & Deci, 2020; Santana-Monagas et al., 2022; Taylor & Ntoumanis, 2007), with meta-analyses and reviews concurring that teacher autonomy support, in particular, is most beneficial (Ryan & Deci, 2020; Slemp et al., 2024). However, there remains a gap in understanding the impact of individual differences in the level of autonomy support needed for optimal individual functioning, as students may differ in the level of support they require.

Educational theories on student engagement, student learning, and school dropout concur that the quality of student behavior is determined by the complex interplay between student and environment characteristics, in what is generally called "person-environment fit" or "stress" processes (Choi, 2004; Fraser & Fisher, 1983; Fraser & Rentoul, 1980; Gilbreath et al., 2011; Hunt, 1975; Núñez et al. 2015; Núñez-Regueiro 2017; Núñez-Regueiro et al., 2022). Derived from Lewin's holistic approach to human behavior (Lewin, 1951), it is posited that the impact of environmental supplies, such as teacher autonomy support, on student need satisfaction in school is closely tied to the specific psychological needs of each student. This raises critical questions: Does satisfaction occur when needs and supplies are balanced, even at low levels of both? Or is it the relative difference between needs and supplies that matters, where an excess of supplies always leads to fulfillment and a deficit of

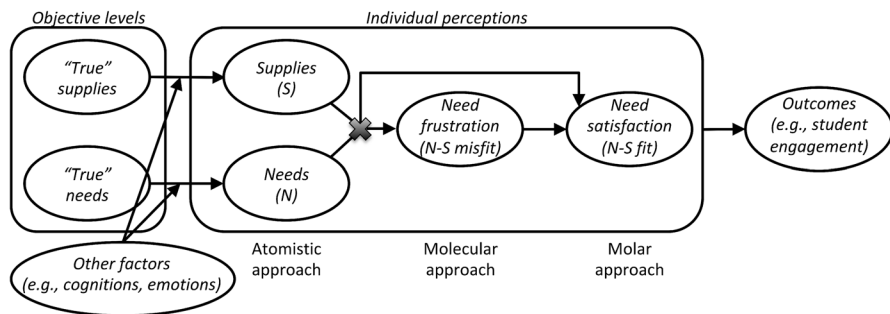
supplies always leads to frustration? Could these relationships involve more complex, nonlinear processes where significant effects emerge only at extreme levels of needs-supplies fit or misfit—potentially in asymmetric or unexpected ways? Alternatively, do individual differences in needs have no significant role in explaining need satisfaction, as is often assumed? No SDT study has yet tested whether the perceived amount of needed supplies, such as a low needs for autonomy support, significantly affects need satisfaction processes or whether these needs alter the impact of supplies in a linear or nonlinear way. This research aims to investigate how processes of fit between student needs for autonomy and teacher autonomy-supportive behavior determine the perceptions of autonomous learning and competence at school (i.e., autonomy and competence need satisfaction), by comparing both linear and nonlinear (quadratic, cubic) patterns of needs-supplies fit processes.

## 2 What relates environmental supplies to need satisfaction? The hidden role of individual differences in psychological needs

The alignment between environmental characteristics (e.g., teacher behavior) and personal characteristics (e.g., student needs) can be assessed using various measurement approaches (for reviews see Edwards et al., 2006; Fraser & Fisher, 1983). The phenomenology of person-environment fit (Edwards et al., 2006) offers an integrative conceptual framework to relate these measurement approaches together, notably in relation to need satisfaction processes. In this section, we apply this phenomenology to the case of needs-supplies fit, and argue about the importance of incorporating individual variations in needs into SDT, notably to develop a more thorough theoretical framework for need satisfaction processes.

### 2.1 The phenomenology of needs-supplies fit: revealing individual needs differences in need satisfaction processes

Within the phenomenology of needs-supplies fit, three major measurement approaches can be defined (see Fig. 1; Edwards et al., 2006). The first approach relates to “atomistic” measures of N-S fit, which correspond to the perceptions of levels of needs or supplies (Fig. 1). From the standpoint of the individual, atomistic measures answer the question: “How much of the characteristic [of needs, of supplies] do I perceive?” Atomistic measures can be obtained by asking students to rate their preferred teaching styles (perception of needs) and the teaching styles they actually received (perception of supplies) (Aldridge et al., 2024; Choi, 2004; Fraser & Fisher, 1983; Fraser & Rentoul, 1980; Gilbreath et al., 2011). By contrast, molecular measures of N-S fit correspond to perceptions of need frustration, and relate to the question: “How much *discrepancy* is there between what I need and what the environment supplies?”. Examples include feelings of futility at school, when students feel they are not receiving the best educational opportunities (e.g., devalued tracking, underprivileged school) and feel frustrated by this (Brookover et al., 1979; Van Houtte & Stevens, 2008). Conversely, molar approaches to N-S fit relate



**Fig. 1** Phenomenology of needs-supplies fit processes. *Note* True amounts of needs and supplies (objective levels) influence the experience of needs-supplies processes (individual perceptions) that, in turn, influence individual outcomes (adapted from the phenomenology of person-environment fit processes, Edwards et al., 2006)

to perceptions of need satisfaction, addressing the question: “How much adequacy or congruence is there between what I need and what the environment supplies?”. Examples include measures of self-efficacy or expectancies (perceived fit between available skills and school-required tasks) and valence (perceived fit between school activities and personal goals or values) (Bandura, 1977; Eccles et al., 1983).

A important insight from analyses of the phenomenology of N-S fit (Edwards et al., 2006) is that perceptions of satisfaction of one’s needs (i.e., a molar measure of fit) are not simply dependent on perceived supplies (e.g., supplies in behavior that support one’s autonomy), but are also shaped by perceived needs (e.g., one’s specific level of needs for autonomy) and on the complex interplay between perceived needs and supplies (see Fig. 1). The interplay between these two elements may be non-linear in various ways. For example, past research has shown that for some N-S fit processes, the relationship was quadratic (or symmetric), where excess supplies (vs. needs) was most conducive to high levels of need satisfaction, and where a matching of supplies (supplies = needs) or deficient supplies (supplies < needs) led to rapidly declining levels of need satisfaction. In contrast, for other N-S fit processes, precise matching supplies was most conducive to high levels of need satisfaction, while both deficient and excessive supplies resulted in lower levels of satisfaction (Edwards et al., 2006).

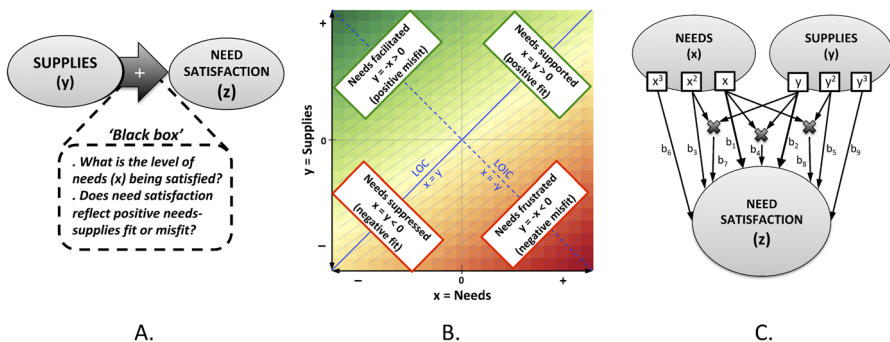
Furthermore, although not previously considered (Edwards et al., 2006), we propose that cubic (or asymmetric) nonlinearities might provide a more nuanced understanding of how variations in needs-supplies fit or misfit influence need satisfaction (see Sect. 3.1). For example, this would be the case when excess supplies (supplies > needs) initially enhance satisfaction but eventually plateau and decline at very high levels (e.g., large excess causing overwhelm and pressure); and when, simultaneously, deficient supplies (supplies < needs) initially reduce satisfaction, worsening with larger deficits but plateauing at extreme lows (e.g., large deprivation causing resignation and numbness to further deprivation). This asymmetry would reflect an S-shaped curvature accounting for threshold effects on both positive misfit (excess supplies) and negative misfit (deficient supplies). By contrast, a quadratic model,

with its symmetric U-shaped (or inverse U-shaped) curvature, would not fully capture this asymmetry and might even result in spurious findings (see Results). The phenomenology of N-S fit can therefore be explored more thoroughly by incorporating both quadratic and cubic nonlinearities, which provide a more comprehensive understanding of how excess or deficient supplies contribute to need satisfaction or undermine it.

A takeaway message is that the relation between atomistic (levels of needs and supplies) and molar measures (need satisfaction) of fit is not systematic and may differ from expectations. In the context of SDT, it might even be the case that supplying students with high levels of needs-supportive behavior is not ideal for some students, as this will create situations that might be detrimental to need satisfaction depending on their levels of needs (e.g., by creating threshold effects in relation to excess or matching supplies). This highlights the importance of accounting for individual differences in perceived needs, which have been overlooked in SDT research on need satisfaction, until now.

### 2.2 Towards atomistic models of need satisfaction processes in self-determination theory

In SDT studies, the degree of fit in needs-supplies processes is assessed in relation to individual variations in need satisfaction, which adheres with a molar measurement approach (i.e., perceptions of needs-supplies fit). Many studies have also reported a positive relation between need satisfaction and the supplies provided by the environment (see Fig. 2A). In particular, teacher autonomy-supportive behavior seems most important to satisfy all three basic psychological needs for autonomy, competence and relatedness ( $r = [.38, .46]$ , according to a recent meta-analysis; Slemp et al., 2024), because teachers with autonomy-supportive behavior not only support autonomy satisfaction, but are also “more attuned to students’ perspectives, allowing



**Fig. 2** Standard (A) versus proposed approach (B, C) to need satisfaction processes in self-determination theory. Note LOC=line of congruence (needs = supplies); LOIC=line of incongruence (needs = -supplies). The “black box” of need satisfaction in self-determined behavior (2A; Deci & Ryan, 2000; Ryan & Deci, 2017) is opened in the form of a needs-supplies spectrum (2B), and related to need satisfaction using cubic polynomial regression modeling (2C; Núñez-Regueiro & Juhel, 2022a, 2024c, 2024d). Specific hypotheses for response surface analysis are presented in Fig. 4

more responsiveness to relational and competence concerns” that satisfy relatedness and competence needs (Ryan & Deci, 2020, p. 4). This positive relation has been shown for diverse populations (i.e., elementary and secondary school students, college students) and countries (e.g., China, Belgium, Korea, Peru, Spain, USA), thus demonstrating its strong generalizability (Chen et al., 2015; Jang et al., 2016; Núñez et al., 2015; Ryan & Grolnick, 1986; Slemp et al., 2024).

Yet, none of these studies has offered a measurement of individual autonomy needs that might have provided an atomistic measurement of N-S fit (see Fig. 2B), thus leaving important questions unanswered. First, by favoring a molar approach to N-S fit (i.e., measures of need satisfaction), it remains unclear which level of individual needs (high, low, intermediate) is being satisfied by the supplies within autonomy-supportive contexts. Second, it is unknown whether need satisfaction predominantly arises from positive misfit (i.e.,  $supplies > needs$ , top-left quadrant of Fig. 2B), positive fit ( $supplies = needs > 0$ , top-right quadrant of Fig. 2B), or both. Without this information, it remains uncertain whether an abundance of supplies is generally beneficial for individual development, or whether such abundance might become maladaptive at extreme levels. A useful analogy comes from physiological processes: while nutrients like calories are essential for growth and energy, their excessive intake can lead to maladaptive outcomes (e.g., such as diabetes, cardiovascular issues, or musculoskeletal strain). Similarly, in autonomy-supportive settings, moderate excess supplies could be helpful, but excessive supplies could eventually overwhelm a student’s needs for autonomy, leading to a ceiling effect. For example, if a teacher excessively provides autonomy support—perhaps due to overconfidence in the student’s maturity—, it could overwhelm the student’s needs for autonomy. This might lead to a breakdown in academic adjustment, particularly if the student is in an early developmental stage and does not feel “ready” for increased autonomous learning (as per stage-environment fit theory; Eccles et al., 1993).

Third, and conversely, relative deficits in autonomy support ( $supplies < needs$ , bottom-right quadrant of Fig. 2B) may undermine competence and autonomy satisfaction with varying intensity, depending on the degree of deficits. For instance, students experiencing moderate deficits in autonomy support might initially feel increasingly frustrated in their needs, but as deprivation becomes extreme they may “shut down” emotionally and be indifferent to further deprivation, leading to a floor effect. This would be akin to how extreme deprivation in physiological systems, such as prolonged starvation, results in diminished sensations of hunger or even loss of consciousness. As detailed later (Sect. 3.1), these nonlinearities in positive and negative misfit likely operate simultaneously, creating asymmetries in how autonomy and competence satisfaction are achieved. Understanding the role of individual needs is therefore crucial to uncover the psychological underpinnings of need satisfaction processes, which currently remain a “black box”.

We propose a theoretical extension to SDT that recognizes the importance of student differences in needs for autonomy support. This extension builds on measures gauging autonomy-supportive behavior, such as teaching focused on taking students’ perspective when presenting the course material, and providing a sense of choice and ownership in learning activities (Jang et al., 2016; León et al., 2023; Núñez-Regueiro et al., under review; Reeve et al., 1999; Ryan & Deci, 2020). What remains

to be developed is a strategy for measuring student differences in the need for such autonomy-supportive contexts. In their pioneering work, Fraser and Rentoul developed a method consisting in measuring students' preferred (needs) versus perceived (supplies) levels of class climate characteristics (e.g., personalization, participation, investigation, differentiation, independence) (Fraser & Rentoul, 1980). We adopt a similar atomistic measurement approach that differentiates preferred versus perceived levels of autonomy-supportive teaching behavior, by adapting the short-version of the Learning Climate Questionnaire on teacher autonomy support (Jang et al., 2016; Williams & Deci, 1996; see Table 1).

### 3 Opening the “black box” of need satisfaction processes using cubic response surface analysis

#### 3.1 Linear, quadratic, and cubic relations of needs-supplies fit or misfit to need satisfaction

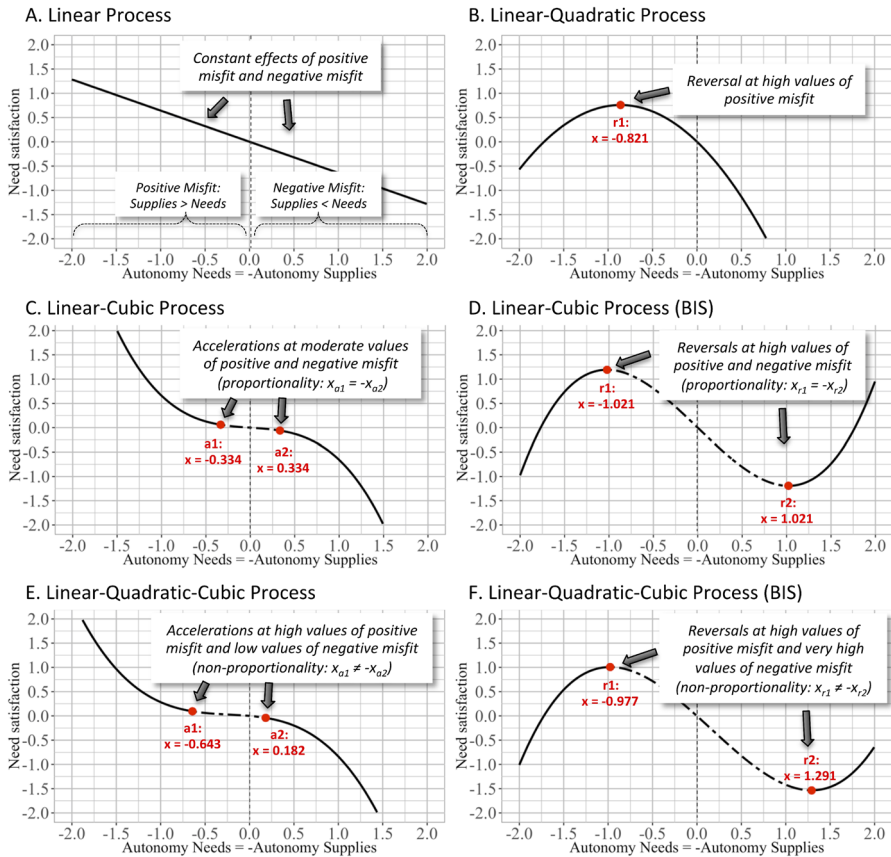
The goal is to better understand how situations reflecting N-S fit or misfit relate to need satisfaction. Although SDT has not yet delved into these processes, research on person-environment fit provides a preliminary basis for theory building. We focus first on N-S misfit processes, that is, when needs and supplies levels differ. Such processes inform on the extent to which deviations from fit (i.e., positive or negative misfit) are optimal or suboptimal for individual behavior (Cable & Edwards, 2004). In its linear variant (Fig. 3A), studies have found that N-S misfit is negatively related to positively valenced outcomes, and that the relation is constant or near constant over the range of congruent needs and supplies values (Choi, 2004; Edwards et al., 2006; Gilbreath et al., 2011; Vogel et al., 2020). Therefore, the beneficial effect of experiencing more supplies than needs increases monotonically as a function of the surplus in supplies. In terms of satisfaction of students' needs, this variant assumes that the more teacher autonomy support is provided, the better the chances of meeting students' needs. In a sense, this variant does not fundamentally change SDT's conception of needs-supportive contexts, i.e., “the more support, the better”. What is added is the existence of needs (currently ignored in SDT) that provide the benchmark against which supplies prove sufficient or insufficient.

In contrast, the linear-quadratic variant (Fig. 3B) reflects findings that the effects of misfit tends to diminish and reverse in valence at extreme levels (Cable & Edwards, 2004; Choi, 2004; Edwards et al., 2006; Gilbreath et al., 2011). The location and interpretation of the reversal point differs across studies, leading to two main interpretations (Cable & Edwards, 2004). If the reversal occurs near central values (i.e.,  $needs = -supplies = 0$  in Fig. 3B), a parabolic pattern emerges, suggesting that experiencing N-S fit maximizes need satisfaction. This means that a student's needs are best met when the teacher provides the right amount of autonomy support—neither too much nor too little—, relative to students' preferences. Conversely, if the reversal occurs at high values of positive misfit (as in Fig. 3B), it suggests that while positive misfit may initially be optimal, its benefits diminish or even become harmful when the excess in supplies becomes extreme (asymptotic pattern).

**Table 1** Atomistic measures of needs and supplies in teacher autonomy support

Scale	Dimension	Item stem	Items
Learning Climate Questionnaire (Williams & Deci, 1996)	Supplies for teacher autonomy support	We would like to know more about how you have felt about your encounters with your instructor	My teacher provides me with choices and options
			My teacher conveys confidence in my ability to do well in this course
Needs-Supplies in Teacher Autonomy Support (NS-TAS)	Needs for teacher autonomy support	In my view, to help me learn in the best way, a good < discipline > teacher should...	My teacher encourages me to ask questions
			I feel understood by my teacher
Needs-Supplies in Teacher Autonomy Support	Supplies for teacher autonomy support	In reality, the fact is that my < discipline > teacher...	My teacher listens to how I would like to do things
			Provide me with choices and options
Needs-Supplies in Teacher Autonomy Support	Supplies for teacher autonomy support	In reality, the fact is that my < discipline > teacher...	Convey confidence in my ability to do well in this course
			Encourage me to ask questions
Needs-Supplies in Teacher Autonomy Support	Supplies for teacher autonomy support	In reality, the fact is that my < discipline > teacher...	Make me feel understood
			Listen to how I would like to do things
Needs-Supplies in Teacher Autonomy Support	Supplies for teacher autonomy support	In reality, the fact is that my < discipline > teacher...	Provides me with choices and options
			Conveys confidence in my ability to do well in this course
Needs-Supplies in Teacher Autonomy Support	Supplies for teacher autonomy support	In reality, the fact is that my < discipline > teacher...	Encourages me to ask questions
			Makes me feel understood
Needs-Supplies in Teacher Autonomy Support	Supplies for teacher autonomy support	In reality, the fact is that my < discipline > teacher...	Listens to how I would like to do things
			Provides me with choices and options

Based on a actual versus preferred classroom climate measurement framework (Fraser & Rentoul, 1980), the Needs-Supplies in Teacher Autonomy Support scale was adapted from the Learning Climate Questionnaire (Jang et al., 2016; Williams & Deci, 1996; see also Aelterman et al., 2019) and validated for strict factorial invariance across needs and supplies measures (Núñez-Regueiro & Juhel, 2024a)



**Fig. 3** Illustration of linear and nonlinear needs-supplies misfit in need satisfaction. *Note*  $x$  = needs. “ $x$ ” values correspond to coordinates on the *needs* = *-supplies* scale for reversal (“r”) or acceleration points (“a”) in nonlinear processes. Similar nonlinearities can be conjectured for N-S fit processes. Integrative study hypotheses are provided in Fig. 4

This could happen if a student’s need satisfaction system can regulate high levels of autonomy support, using what is necessary and disregarding the excess. However, extreme levels of excess may become counterproductive, as a student might feel overwhelmed by too much autonomy. This is similar to water intake: While the body can regulate excess water for optimal hydration, consuming too much can lead to adverse effects like high blood pressure and low heart rate (for similar example with caloric intake, see Sect. 2.2).

While linear and linear-quadratic models have typically been used to model N-S misfit, they overlook potential cubic processes. For example, low levels of misfit might not significantly affect need satisfaction, as they may be too subtle to distinguish from a situation of fit. Just as the body can effectively regulate small variations in caloric intake—storing excess calories or drawing on reserves to compensate for minor deficits—small mismatches between autonomy supplies and needs may have

little impact. Thus, slight deficits in autonomy support might be inconsequential if the student compensates by gaining this support elsewhere (e.g., from peers or family). Similarly, minor excesses in autonomy support may be easily integrated, allowing the student to adapt without significant disruption to their competence or autonomy satisfaction. This would imply that the effects of positive and negative misfit only become significant at certain acceleration points, as posited by a (negative) linear-cubic process (Fig. 3C).

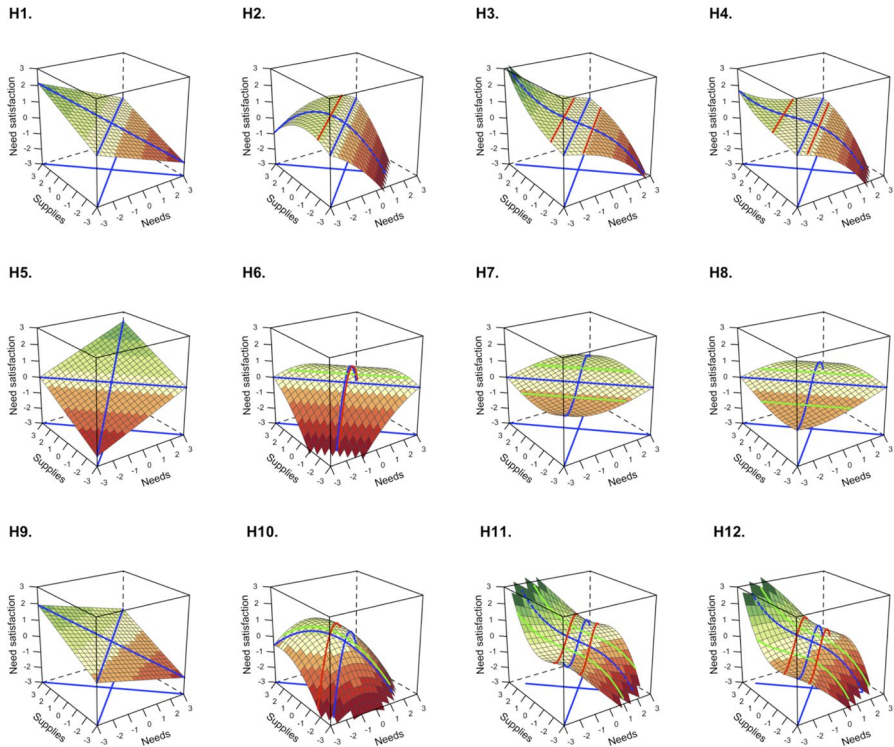
Moreover, the reversal effects seen at high levels of positive misfit (Fig. 3B) could also occur at high levels of negative misfit, as proposed by a positive linear-cubic process (Fig. 3D). This could happen if students' need satisfaction reaches a low point with severe deprivation in teacher autonomy support, where further deprivation has no significant impact anymore (aforementioned floor effect, see Sect. 2.2). These cubic processes can be further refined by including a quadratic effect, which adjusts the location of reversal or acceleration points across positive or negative misfit values. For instance, the effects of N-S misfit on need satisfaction might occur at high levels of excess supplies (positive misfit), but at low levels of deficit supplies (negative misfit; Fig. 3E). Similarly, reversal effects might appear at high levels of positive misfit, but only at very high levels of negative misfit (Fig. 3F).

Similar rationales for linear, quadratic, or cubic processes (and their combinations) can be used to guide the modeling of needs-supplies fit effects, where needs and supplies levels are the same. Studies most often find a positive trend, in which positive N-S fit (i.e., high needs met by high supplies) yield more positive outcomes than negative N-S fit (i.e., low needs met by low supplies; Cable & Edwards, 2004; Choi, 2004; Gilbreath et al., 2011; Vogel et al., 2020). Yet, reversals in N-S fit have been observed at both positive (Choi, 2004) and negative (Gilbreath et al., 2011) extremes. Positive N-S fit reversals suggest diminishing benefits for need satisfaction (ceiling effect), notably in contexts of academic press (from parents, curriculum) where barely fitting autonomy-supportive teaching may be too austere and trigger burnout symptoms (Bask & Salmela-Aro, 2013; Núñez-Regueiro, 2017). Conversely, negative N-S fit reversals reflect diminishing losses (floor effect), as students facing boredom or helplessness in autonomy-suppressive teaching contexts lower their expectations (Buzzai et al., 2021; Núñez-Regueiro, 2017). Despite these patterns, cubic processes in N-S fit processes remain unexplored.

### 3.2 A set of twelve study hypotheses based on cubic response surface analysis

Based on cubic polynomial regression and N-S fit theory (see previous section), we derive 12 study hypotheses about linear or nonlinear processes of N-S fit or misfit (see Fig. 4 and Table 2). These hypotheses incorporate previous findings on person-environment fit processes and adapt them to the analysis of need satisfaction processes in SDT. For clarity, we differentiate hypotheses focused on N-S misfit (H1-H4) and misfit (H5-H8), before uniting them in hypotheses including both fit and misfit processes (H9-H12).

*Supplies differ from needs (N-S misfit).* The first set of hypotheses (H1 to H4, Fig. 4) suggests that need satisfaction is influenced N-S



**Fig. 4** Study hypotheses about needs-supplies fit and misfit processes undergirding need satisfaction. *Note*  $x = \text{needs}$ ;  $y = \text{supplies}$ . Parameters  $b_1$  to  $b_9$  are defined as in Fig. 2C (see also Table 2). Lines correspond to hypotheses assuming a beneficial effect of positive misfit ( $x < y$ ; line 1), positive fit ( $x = y$ ; line 2), and positive fit or misfit ( $x \leq y$ ; line 3). Columns correspond to linear (1), quadratic and linear (2), cubic and linear (3), and cubic, quadratic, and linear (4) variants of the hypotheses. Dashed and solid lines describe the response surface above the line of congruence (LOC,  $x = y$ ) and line of incongruence (LOIC,  $x = -y$ ), respectively. Lines in green and red intersect inflection points on the LOC and LOIC, respectively

misfit where supplies either exceed needs ( $\text{supplies} = -\text{needs} > 0$ ), or fall short ( $\text{supplies} = -\text{needs} < 0$ ; see Fig. 2B). These hypotheses share the common assumption that the degree of N-S fit, whether positive or negative, does not directly impact need satisfaction. However, they differ with regard to their linear or nonlinear patterns. The linear hypothesis (H1) posits a consistent, beneficial effect of an excess in supplies (as shown in Fig. 3A). The linear-quadratic hypothesis (H2) posits that this beneficial effect is present only up to a certain degree of excess, after which it diminishes and reverses (Fig. 3B). In contrast, the linear-cubic hypothesis (H3) proposes that the beneficial effect of excessive supplies—and, conversely, the harmful effect of insufficient supplies—becomes significant only at larger, with the process accelerating as misfit increases (Fig. 3C). The last hypothesis (H4) introduces a non-proportionality in this acceleration process, where the detrimental effect of negative misfit occurs

**Table 2** Overview of parametric constraints and polynomial families of study hypotheses

Kind of Hypotheses	Parametric Constraints	Polynomial Family
<i>Need satisfaction as reflecting variations in needs-supplies misfit</i>		
H1. Linear	$-b_1 = b_2 > 0$ ;	Additive effects
H2. Linear-quadratic	$-b_1 = b_2 > 0$ ; $b_3 = \frac{b_4}{-2} = b_5 < 0$ ;	Congruence effect
H3. Linear-cubic	$-b_1 = b_2 > 0$ ; $b_6 = \frac{b_7}{-3} = \frac{b_8}{3} = -b_9 < 0$	Asymmetric cong. effect
H4. Linear-quadratic-cubic	H1 + H2 + H3	Same as H3
<i>Need satisfaction as reflecting variations in needs-supplies fit</i>		
H5. Linear	$b_1 = b_2 > 0$	Additive effects
H6. Linear-quadratic	$b_1 = b_2 > 0$ ; $b_3 = \frac{b_4}{2} = b_5 < 0$	Incongruence effect
H7. Linear-cubic	$b_1 = b_2 > 0$ ; $b_6 = \frac{b_7}{3} = \frac{b_8}{3} = b_9 < 0$	Asymmetric incong. effect
H8. Linear-quadratic-cubic	H5 + H6 + H7	Same as H7
<i>Need satisfaction as reflecting variations in needs-supplies fit or misfit</i>		
H9. Linear	sss	Additive effects
H10. Linear-quadratic	$-b_1 = mb_2 > 0$ (with constant $m < 0$ )	Quadratic effects of x and y
H11. Linear-cubic	$b_1 = mb_2$ ; $b_3 < 0$ ; $b_5 < 0$ $b_1 = mb_2$ ; $b_8 = -3 * b_9 < 0$	Parallel asymmetric weak congruence and strong incongruence effects
H12. Linear-quadratic-cubic	H9 + H10 + H11	Same as H11

Parameters are defined as in Fig. 2C. Parameters not appearing in the hypothesis are fixed to zero. Polynomial families are predefined by non-zero constraints of higher-order polynomials. For a list of 37 families and their respective constraints, see (Núñez-Regueiro & Juhel, 2022a, 2024c)

at low levels of misfit, while the beneficial effect of positive misfit only occurs at high levels (Fig. 3E). This suggests that negative misfit has a more substantial impact on need satisfaction than positive misfit.

*Supplies equal needs (N-S fit).* Conversely, the second set of hypotheses (H5 to H8, Fig. 4) posits that need satisfaction is driven solely by N-S fit, where low supplies match low needs ( $supplies = needs < 0$ ) and high supplies match high needs ( $supplies = needs > 0$ ; Fig. 2B). These hypotheses assume that N-S misfit does not affect need satisfaction. However, they differ in whether they assume a linear or nonlinear relationship between N-S fit and need satisfaction. The linear hypothesis (H5) suggests that N-S fit has a consistent, positive effect on need satisfaction, aligning with previous research (Cable & Edwards, 2004; Choi, 2004; Gilbreath et al., 2011; Vogel et al., 2020). The linear-quadratic hypothesis (H6) proposes that this positive effect diminishes and reverses at high levels of N-S fit, possibly due to the maladaptive effects of extremely high needs (Gilbreath et al., 2011). The linear-cubic hypothesis (H7) extends this by suggesting that the reversal effect also occurs at low levels of N-S fit (Choi, 2004). Finally, the linear-quadratic-cubic hypothesis (H8) refines this process by introducing non-proportionality, indicating that the reversal for positive N-S fit occurs closer to average values, while the reversal for negative N-S fit happens later. This suggests that the detrimental effects of negative N-S fit persist over a wider range of values than the beneficial effects of positive N-S fit, which reverse more rapidly.

*Supplies equal or differ from needs (N-S fit or misfit).* The third kind of hypotheses (Fig. 4, H9 to H12) corresponds to the combinations of linear (H9 = H1 + H4), linear-quadratic (H10 = H2 + H6), linear-cubic (H11 = H7 + H11), and linear-quadratic-cubic hypotheses (H12 = H4 + H8) previously described for misfit and fit processes. Therefore, the interpretation along the lines of fit or misfit is the same as before (i.e., as for H1 to H8). What changes is the assumption that both processes of fit and misfit determine need satisfaction processes. Another assumption of these hypotheses, particularly visible in H9, is that the main trend along the line of misfit is larger in effect size (i.e., more impactful for need satisfaction) than the trend along the line of fit.

Taken together, the 12 hypotheses provide a guide for understanding the complexity of nonlinearities in N-S fit processes. They are, in this sense, “prototypical” of what could be expected. However, they only represent a subset of possible combinations of families of polynomials. For example, although non-proportionality in H4, H8, and H12 was specified to reinforce the effects of negative fit or misfit, it could be that the empirical data follow a reverse non-proportionality, which would imply positive instead of negative second-order polynomial effects. Similarly, obtaining good fit between the response surface and the data could require the addition or modification of parametric constraints, or even alternative families of polynomial than those assumed in Table 2 (e.g., level-dependent congruence or incongruence processes). The comparative framework for cubic RSA, which compares the relative fit of linear, quadratic, or cubic response surface (see Method), is therefore most warranted to account for both expected and unexpected N-S fit processes.

## 4 Present study

This study aimed to elucidate the relation between needs-supplies fit processes and need satisfaction in the school context, specifically students' autonomy and competence satisfaction. Theoretically, we aimed to discern whether need satisfaction depends on student differences in the levels of needs and, if so, whether autonomy satisfaction (or competence satisfaction) reflects situations of high needs and high supplies in teacher autonomy support (positive fit), situations of higher supplies than needs (positive misfit), or a combination of both. Methodologically, we sought to explore the application of cubic RSA for the first time in investigating needs-supplies fit in need satisfaction processes at school. Two research questions guided the analysis:

RQ1: Does need satisfaction depend on individual needs, in the form of positive misfit or fit between student needs and teacher supplies in autonomy support?

RQ2: Are there nonlinearities in the relations of N-S (mis)fit processes to need satisfaction?

The first research question (RQ1) was guided by the 12 hypotheses on N-S fit processes (H1 through H12; Fig. 4). Thus, we expected one of these hypotheses to explain need satisfaction processes, so that positive fit (H1-H4), positive misfit (H5-H8), and both positive fit and misfit processes (H9-H12) would occur according to linear (additive effects), linear-quadratic (curved process), linear-cubic (asymmetric process), and linear-quadratic-cubic relations (non-proportional, asymmetric process). However, given the complexity of response surfaces, the expectation was also that the empirical data might yield alternative nonlinearities in the response surface. Concerning RQ2, we expected that nonlinear relations would contribute in a nontrivial way to differences in need satisfaction, by providing important information about N-S (mis)fit processes (e.g., reversals, accelerations) not accounted for by a linear model.

## 5 Method

### 5.1 Participants

Participants were 398 students [ $M(\text{age})=14.3$ ,  $SD(\text{age})=2.1$ , 58% female adolescents] from 3 schools (37 classes) in the French Alps. The sample covered all grade levels of secondary school (i.e., grades 6 through 12,  $n=[57, 68]$ ), and was from low or intermediate (school 1,  $n=96$ ), intermediate (school 2,  $n=191$ ), and high SES background (school 3,  $n=111$ ). Although no outliers were detected in the data (i.e., per hat diagonal index, DFITs, or Cook's  $d$ ; Bollen & Jackman, 1985; Edwards, 2002), 2% of careless respondents were identified through excessively rapid and inconsistent responses (Ward & Meade, 2023). The final sample consisted of 389 students. According to sensitivity analyses based on the increase in explained variance associated with including higher-order polynomial

parameters (i.e.,  $b_3$  to  $b_9$ ), this sample had sufficient power to detect quadratic and cubic nonlinearities hypothesized in Fig. 4, even of small effect sizes (i.e.,  $\Delta R^2 = 3.6\%$ ; Faul et al., 2009).

## 5.2 Procedure

Consent for the study was obtained from the university ethic committee, district leaders, and headmasters of the participating schools. Data collection utilized an online questionnaire comprising 65 items, launched through the schools' administrative mailing lists for their students. Participation in the study was voluntary and anonymous. On average, students took approximately 8 min to complete the questionnaire.

## 5.3 Measures

Statistics for students' needs, supplies, and need satisfaction are reported in Table 3. Measurement models of study variables are provided in Table S1, Supplemental Material (SM).

*Teacher autonomy support supplies and needs.* Levels of needs and supplies in teacher autonomy support were measured using the NS-TAS scale (Núñez-Regueiro & Juhel, 2024a). This scale uses a parallel set of items to characterize teacher autonomy support with 5 items of the short version of the Learning Climate Questionnaire (Jang et al., 2016; Williams & Deci, 1996), and is tailored to a discipline, in this case one of two disciplines (language arts or mathematics, assigned randomly). Respondents answered each item based on a 5-point Likert scale (1 = do not agree at all, 5 = very strongly agree). Each item was addressed twice: once to assess ideal levels of teacher autonomy support (needs), and once to assess the actual levels perceived (supplies). Through repeated-measures confirmatory factor analyses, factors of needs ( $\omega_{needs} = .710$ ) and supplies ( $\omega_{supplies} = .885$ ) showed excellent fit to the data (e.g., CFI = 0.976, RMSEA = 0.047) and demonstrated strict invariance in their relations to the parallel set of items (e.g.,  $\Delta CFI > -0.006$ ,  $\Delta RMSEA < 0.008$ ; Chen et al., 2015; Maassen et al., 2023). This invariance encompassed factor loadings, item intercepts, and uniquenesses, highlighting their commensurability for needs-supplies fit modeling (Núñez-Regueiro & Juhel, 2024a).

**Table 3** Descriptive statistics

	M	SD	Theoretical range	1	2	3
1. Needs in teacher autonomy support	4.178	0.632	[1, 5]			
2. Supplies in teacher autonomy support	3.215	1.051	[1, 5]	.143**		
3. Autonomy satisfaction	3.314	0.964	[1, 5]	.050	.448***	
4. Competence satisfaction	3.783	1.038	[1, 5]	.144**	.302***	.588***

N = 389 secondary school students

\*\* $p < .01$ . \*\*\* $p < .001$

*Autonomy and competence need satisfaction.* Autonomy and competence need satisfaction were assessed in the same discipline as needs and supplies (i.e., language arts or mathematics). This was achieved by incorporating an item stem specifying the discipline to be considered, for instance, *In my [discipline] class, [item]*. Students expressed their degree of agreement with each item on a 5-point scale (1 = “do not agree at all”, 5 = “very strongly agree”). More precisely, autonomy satisfaction was based on 3 items adapted from autonomy satisfaction scales (i.e., *I feel free to express myself or ask questions, I feel autonomous in carrying out my work, I feel that I am doing something that really interests me*; Chen et al., 2015; Jang et al., 2016), which showed strong factor loadings ( $.525 < \beta < .724$ ) but borderline acceptable consistency ( $\omega_{\text{autonomy}} = .649 \leq .65$ ; DeVellis, 2016). To mitigate the impact of measurement error, the decision was made to extract factor scores, thereby retaining only the “true” variance in feelings of autonomy in the class. Competence satisfaction was measured using the scale of Perceived competence for learning (Williams & Deci, 1996), a 4-item scale demonstrating strong internal consistency ( $\omega_{\text{total}} = .923$ ) and excellent fit to the data (e.g., CFI = 1.000, RMSEA < 0.001).

*Covariates.* The survey also measured potential confounding factors of need satisfaction, including adolescents’ age, gender (1 = “female adolescent”), parental education level (1 = “Primary school” to 4 = “Higher education”), grade point average (GPA) in the course specific to needs-supplies fit processes (21-point scale) and in all courses considered (21-point scale), and educational level (0 = “middle school”, 1 = “high school”).

## 5.4 Analytic strategy

*Response surface analysis.* Needs-supplies fit processes of need satisfaction were identified using a comparative framework for response surface analysis, based on a 3-step identification strategy (Núñez-Regueiro & Juhel, 2022a). Aligning with a comparative approach (Schönbrodt, 2016), Step 1 involves selecting the best-fitting solution from among 37 families of polynomials. These families are characterized by constraints applied to first-order ( $b_1, b_2$ , with  $b_3 : b_9$  fixed to zero), second-order ( $b_3, b_4, b_5$ , with  $b_6 : b_9$  fixed to zero), or third-order polynomial parameters ( $b_6, b_7, b_8, b_9$ ) of the cubic model (Núñez-Regueiro & Juhel, 2024c). Lower-order parameters specific to each family are freely estimated, which allows for higher-order families (third-order, second-order) to combine with lower-order families (second-order, first-order) across thousands of possible processes, either expected (confirmatory hypothesis, as in Fig. 4) or unexpected (exploratory hypothesis). Best-fitting solutions are selected based on tests of absolute fit against the saturated cubic model, on parsimony and explanatory power indices (i.e., AIC weights, adjusted R<sup>2</sup>), on the significance of the family-specific parameters, and on evidence of good fit to the data using the benchmark values of CFI  $\geq 0.95$ , TLI  $\geq 0.95$ , RMSEA  $\leq 0.06$ , SRMR  $\leq 0.08$  (Hu & Bentler, 1999). This effectively allows determining which among the linear, quadratic, or cubic polynomial families provides the best representation of the data for RSA. Step 2 then identifies the best-fitting variant within the best-fitting family, by testing equality or zero constraints on lower-order polynomial parameters in that

family using likelihood ratio tests between nested models (Humberg et al., 2022). In Step 3, the robustness of results from the model-selection processes conducted in Steps 1 and 2 is assessed. This is done by utilizing 1000 bootstrapped samples and ensuring that the obtained 95% CI of non-null parameters in the best-fitting variant does not contain the value zero (Huang, 2020; Xu & Goodacre, 2018). In this study, we also integrated background covariates into the final model (Step 4), to assess its robustness to student background characteristics.

The best-fitting variant was then interpreted by probing the curvatures of the response surface, using reversal points “r” where the behavior changes valence, and acceleration points “a” where the response undergoes a notable change in behavior (Humberg et al., 2022; Núñez-Regueiro & Juhel, 2024d). Acceleration points were defined for rates of change reflecting a substantial effect size, i.e.,  $|\frac{\partial z}{\partial x}| = 0.50$  (Cohen, 1988). Reversals and accelerations were identified for students above reversal or acceleration lines, whose need satisfaction significantly contradicted (reversals) or increased (accelerations) from the main trend, as indicated by 95% confidence intervals excluding observed values (Núñez-Regueiro & Juhel, 2024d).

To gain a deeper understanding of the enhanced insights gained by considering the effects of needs and higher-order effects in N-S fit processes, the best-fitting response surface was compared with a linear response surface and a quadratic response surface. One linear variant only included main effects from needs and supplies (additive effects model, FM3), and another linear variant included only the effect of supplies (effect of Y model, FM2). The quadratic surface corresponded to the conventional quadratic RSA (Edwards & Parry, 1993; Shanock et al., 2010) used in previous person-environment fit research (Cable & Edwards, 2004; Choi, 2004; Edwards et al., 2006; Gilbreath et al., 2011).

To limit parametric bias in RSA, all main variables (needs, supplies, need satisfaction) were standardized to zero means and unit variance prior to analysis (Núñez-Regueiro & Juhel, 2024f), and parameters were estimated with a data clustering correction accounting for class-level variance (Muthén & Satorra, 1995). Missing data (8% to 9%) were accounted for using full information maximum likelihood. Data analysis was conducted on the R package *RSAtools* (Núñez-Regueiro & Juhel, 2024e; R Core Team, 2024), based on packages *lavaan* and *ggplot2* (Rossee, 2012; Wickham, 2016).

## 6 Results

### 6.1 Results on needs-supplies fit processes of autonomy satisfaction

*Identification of the best-fitting polynomial model.* The family of level-dependent incongruence effect rotated by Y (FM36, with constraints:  $b_6 = -b_7 = b_8$ ) emerged as the best-fitting candidate among polynomial families (Step 1). It passed the test of absolute fit ( $\chi^2 < 0.1, p = .988$ ), exhibited the largest explained variance ( $R^2 = 15.9\%$ ), demonstrated the best relative parsimony ( $wAIC = .116$ ), and displayed excellent fit indices ( $CFI = 1.000, TLI = 1.284, RMSEA = 0.000$ ,

SRMR=0.001; Table 4). A closely related model (i.e., level-dependent incongruence effect rotated by X) showed almost exactly the same fit, but the former was chosen for its greater coherence with the solution for competence satisfaction (see next section). In contrast, the models that included only the effect of supplies (e.g., CFI=0.860, R2adj=.125), or only linear effects of needs and supplies (e.g., CFI=0.830, R2adj=.123) demonstrated unsatisfactory fit to the data. These models also explained 3 percentage points less variance in autonomy satisfaction and ranked in the lower tier of polynomial families in terms of fit (for details, see SM, Table S2). Similarly, the quadratic polynomial effects of needs and supplies, corresponding to a conventional quadratic RSA, showed an unsatisfactory fit to the data (e.g., CFI=0.838, R2adj=.125). An inspection of parameters from the best-fitting candidate FM36 (Step 2) suggested several equality and zero constraints (i.e.,  $b_2 = 5 * b_1$ ,  $b_3 = b_4 = 0$ ,  $b_9 = b_6$ ; see Model 1, Table 5). By imposing these constraints, a best-fitting variant for FM36 was achieved ( $\chi^2_4 = 0.4$ ,  $p = .982$ ), explaining 16.8% of the variance in autonomy satisfaction. This represented a 35% increase in explained variance compared to the linear model, the supplies-only model, and the quadratic polynomial model.

**Robustness checks.** Bootstrapping procedures (Step 3) indicated that the 95% CIs of parameters from this best-fitting variant did not include zero, supporting valid post-model-selection inferences (Model 3, Table 5). Likewise, model parameters were robust to the inclusion of covariate effects (Model 4, Table 5), indicating they were little sensitive to student characteristics.

**Interpretation of the response surface.** According to the response surface of the linear model (Fig. 5A), autonomy satisfaction was uniformly and equivalently related to processes of positive fit and positive misfit, driven by the positive effect of supplies, which overshadowed the nonsignificant effect of needs (Fig. 5A; see Model 1, Appendix B). In other words, no linear N-S (mis)fit process was identified. Similarly, the quadratic model indicated that neither the parameters, the metaparameters, nor the response surface showed significant curvatures (e.g., accelerations, reversals), leading to the conclusion that no nonlinear N-S (mis)fit process existed (see Fig. 5B and Model 3, Appendix B). However, as previously stated, these models provided poor-fitting solutions.

In contrast, the cubic model of the best-fitting polynomial model (Fig. 5C; see Model 3, Table 5) revealed marked, non-proportional nonlinearities that differed for N-S fit and misfit processes. Along most of the N-S fit axis (LOC axis, Fig. 5C.2), autonomy satisfaction was positively related to high levels of fit. However, upon reaching extrema, the beneficial effect of fit reversed. Specifically, for very low congruent amounts of needs and supplies approximately 2 SD below the mean (i.e., first reversal point situated at  $needs = supplies = -1.896$ ), decreasing N-S fit was associated with higher levels of autonomy satisfaction (3% of students). Conversely, for high congruent amounts approximately 1 SD above the mean (i.e., second reversal point situated at  $needs = supplies = 0.758$ ), increasing N-S fit was associated with lower levels of autonomy satisfaction (9% of students). This latter reversal stood in sharp contrast to the quasi-linear effects of fit misidentified by the quadratic model (see Fig. 5B.2).

**Table 4** Fit indices of polynomial models of autonomy and competence need satisfaction

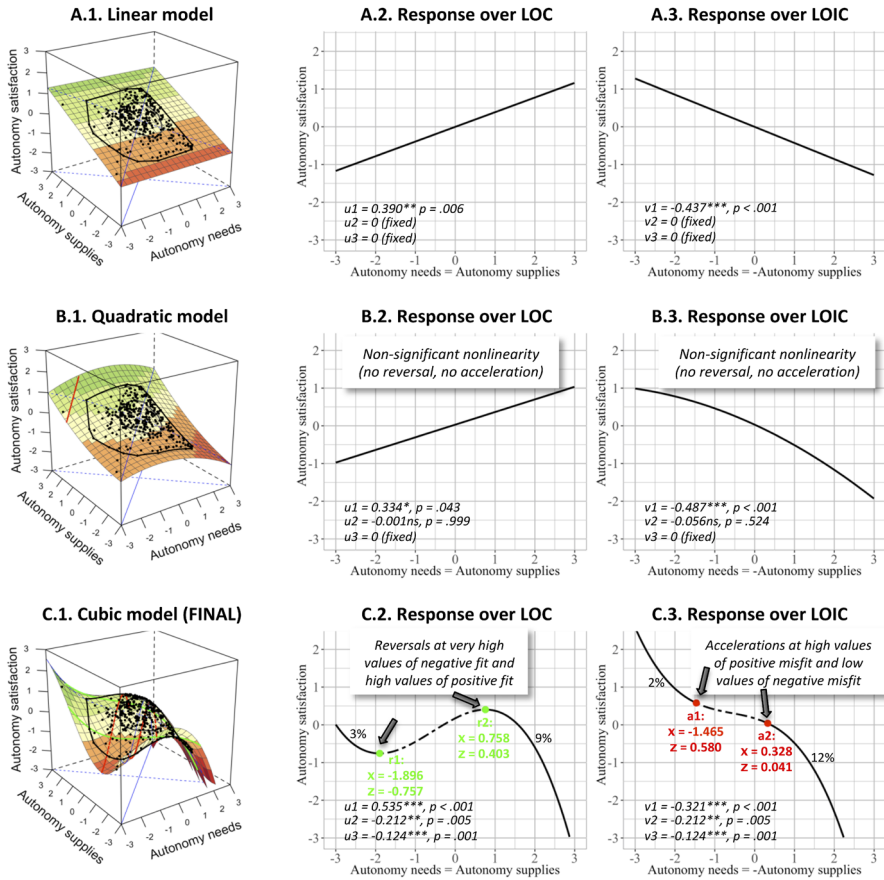
Model	$\chi^2$	df	<i>p</i>	wAIC	wBIC	R <sup>2</sup> adj	CFI	TLI	RMSEA	SRMR
<i>Autonomy satisfaction (perceived autonomy)</i>										
Cubic model (saturated model)	0.0	0	–	.016	.000	.154	1.000	1.000	0.000	0.000
37. Level-dependent incongruence effect rotated by X	0.0	2	.987	.115	.000	.159	1.000	1.284	0.000	0.001
<b>36. Level-dependent incongruence effect rotated by Y</b>	<b>0.0</b>	<b>2</b>	<b>.988</b>	<b>.116</b>	<b>.000</b>	<b>.158</b>	<b>1.000</b>	<b>1.284</b>	<b>0.000</b>	<b>0.001</b>
<i>Best-fitting variant of 36</i>	<i>0.3</i>	<i>6</i>	<i>.999</i>	–	–	<i>.168</i>	<i>1.000</i>	<i>1.274</i>	<i>0.000</i>	<i>0.004</i>
31. Asymmetric congruence effect rotated by X	2.3	2	.318	.037	.000	.151	0.991	0.958	0.020	0.005
24. Parallel, asymmetric congruence and incongruence effects	3.1	3	.377	.068	.000	.150	0.997	0.991	0.009	0.006
<i>Competence satisfaction (perceived competence)</i>										
Cubic model (saturated model)	0.0	0	–	.007	.000	.101	1.000	1.000	0.000	0.000
<b>36. Level-dependent incongruence effect rotated by Y</b>	<b>0.2</b>	<b>2</b>	<b>.913</b>	<b>.045</b>	<b>.000</b>	<b>.106</b>	<b>1.000</b>	<b>1.225</b>	<b>0.000</b>	<b>0.001</b>
<i>Best-fitting variant of 36</i>	<i>0.8</i>	<i>6</i>	<i>.991</i>	–	–	<i>.114</i>	<i>1.000</i>	<i>1.213</i>	<i>0.000</i>	<i>0.005</i>
<i>Best-fitting variant of 36, MODIFIED</i>	<i>4.7</i>	<i>7</i>	<i>.696</i>	–	–	<i>.106</i>	<i>1.000</i>	<i>1.081</i>	<i>0.000</i>	<i>0.010</i>
37. Level-dependent incongruence effect rotated by X	0.4	2	.828	.041	.000	.105	1.000	1.201	0.000	0.002
31. Asymmetric congruence effect rotated by X	0.7	2	.700	.034	.000	.105	1.000	1.159	0.000	0.002
23. Level-dependent incongruence effect	1.8	3	.605	.053	.000	.104	1.000	1.095	0.000	0.004

X = needs; Y = supplies. In plain characters, numbered models correspond to the 4 best-fitting families of fundamental models of congruence, which are compared in Step 1 of the identification strategy (for complete list, see SM). Polynomial models in bold and italic characters correspond to the best-fitting family (Step 1) and the best-fitting variant within the family (Step 2), respectively. The “MODIFIED” model differs from the original best-fitting variant by fixing the quadratic effects of needs ( $b_2$ ) and supplies ( $b_3$ ) to zero (see Table 6 for details)

**Table 5** Parameters of best-fitting polynomial models of autonomy satisfaction

Model	$b_1$	$b_2$	$b_3$	$b_4$	$b_5$	$b_6$	$b_7$	$b_8$	$b_9$
<i>Model 1: Best-fitting polynomial family FM36</i>									
Estimate	0.101	0.446	-0.216	0.005	0.025	-0.061	0.061	-0.061	-0.066
<i>p</i> value	.265	.000	.005	.911	.610	.003	.003	.003	.131
<i>Model 2: Best-fitting variant of FM36</i>									
Estimate	0.107	0.428	-0.212	0	0	-0.062	0.062	-0.062	-0.062
<i>p</i> value	.000	.000	.005	fixed	fixed	.001	.001	.001	.001
<i>Model 3: Best-fitting variant of FM36, bootstrapped</i>									
Estimate	0.106	0.426	-0.223	0	0	-0.065	0.065	-0.065	-0.065
CI 95%	(0.068, 0.146)	(0.274, 0.582)	(-0.349, -0.085)	fixed	fixed	(-0.106, -0.028)	(0.028, 0.106)	(-0.106, -0.028)	(-0.106, -0.028)
<i>Model 4: Best-fitting variant of FM36 with covariates</i>									
Estimate	0.100	0.398	-0.167	0	0	-0.049	0.049	-0.049	-0.049
<i>p</i> value	.000	.000	.032	fixed	fixed	.010	.010	.010	.010

$N = 389$  students. Parameters  $b_1$  to  $b_9$  describe the cubic polynomial effects of needs ( $x$ ) and supplies ( $y$ ) in teacher autonomy support on autonomy satisfaction in a specific discipline ( $z$ : language arts or mathematics). Covariates effects (i.e., age, gender, parental education level, general and course-specific grade point average) are reported in Table S4 (SM). Bootstrapped values correspond to means and 95% confidence intervals (1000 samples)



**Fig. 5** Response surfaces of alternative models of autonomy satisfaction. *Note.* N = 389 secondary school students. LOC = Line of congruence (N-S fit); LOIC = Line of incongruence (N-S misfit). Graphs show the response surface (column 1), response over the LOC (column 2), and response over the LOIC (column 3). Metaparameters  $u_1$  to  $v_3$  correspond to the linear, quadratic and cubic fit or misfit effects (see Appendix A). Green and red lines intersect reversal (“r”) and acceleration points (“a”) on the LOC and LOIC, respectively. Percentages reflect students significantly affected by reversals or accelerations. The fence represents the fourth quartile of the bagplot. Parameters for linear, quadratic, and cubic models are in Appendix B (Models 1 and 3) and Table 5 (Model 2)

Concerning N-S misfit (LOIC axis; Fig. 5C.3), acceleration processes revealed that the beneficial effect of positive misfit became substantial (i.e., of large size,  $\frac{\partial z}{\partial x} > 0.50$ ) for a relative excess of supplies of 3 SD (i.e., first acceleration point at  $needs = -supplies = -1.465$ , or a  $-1.465 * 2 = 2.930$  SD excess in supplies; 2% of students), whereas the detrimental effect of negative misfit became substantial for a relative deficit of supplies of 2/3 SD (i.e., second acceleration point at  $needs = -supplies = 0.328$ , or a  $0.328 * 2 = 0.656$  SD deficit in supplies; 12% of students). In other words, consistent with H12 (Fig. 4), the nonproportionality between acceleration points indicated that the deleterious effect of negative N-S

misfit became noteworthy more quickly than the beneficial effect of positive N-S misfit.

## 6.2 Results on needs-supplies fit processes of competence satisfaction

*Identification of the best-fitting polynomial model.* As for autonomy satisfaction, the fundamental family of level-dependent incongruence effect rotated by Y (FM36) appeared to be the polynomial that best described the data on competence satisfaction (Step 1). This family did not differ from a saturated cubic model ( $\chi^2 = 0.2$ ,  $p = .913$ ), showed the largest explained variance ( $R^2_{adj} = 10.6\%$ ), was among the top 5 families showing the most parsimonious solutions as well as significant family parameters (i.e., FM8, FM12, FM11, FM24, FM36) and, among the latter, showed the best fit indices ( $CFI = 1.000$ ,  $TLI = 1.225$ ,  $RMSEA = 0.000$ ,  $SRMR = 0.001$ ; Table 4). As for autonomy satisfaction, the linear models of additive effects of needs and supplies (e.g.,  $CFI = 0.895$ ,  $R^2_{adj} = .090$ ) or of supplies only (e.g.,  $CFI = 0.827$ ,  $R^2 = .074$ ) had poor fit to the data and ranked among the worst-fitting solutions (see Table S3SM). Again, the conventional, quadratic RSA showed non-significant effects (see Appendix B) as well as poorer fit to the data (e.g.,  $TLI = 0.883$ ,  $R^2_{adj} = .096$ ). An examination of parameters from the best-fitting model FM36 suggested several equality and zero constraints (i.e.,  $b_1 = b_2$ ,  $b_3 = -b_5$ ,  $b_4 = 0$ ,  $b_9 = 0$ ; see Model 1, Table 6). When these were implemented, there were no significant decrements in model fit compared to the unconstrained solution ( $\chi^2_4 = 0.5$ ,  $p = .975$ ). The obtained best-fitting variant (Model 2, Table 6) explained 11.4% of the variance in perceived competence for learning, which represented 27% and 36% increases respectively from the additive model and the supplies only model, and a 19% increase from the quadratic RSA.

*Robustness checks.* Complementary analyses showed that the parameters of the best-fitting variant were robust to bootstrapped sampling (Step 3; Model 3 Table 6) and inclusion of covariates (Step 4; Model 4, Table 6). Exceptions were the quadratic effects of needs and supplies (i.e.,  $b_3$  and  $b_5$ ), which appeared to be vulnerable to model selection procedures (95% CIs contained the value zero) and also became non-significant at 5% after accounting for significant covariates (i.e., general and course-specific GPA; Table S4, SM). To obtain a more robust solution, a new variant was estimated in which these two quadratic effects were fixed to zero. This variant did not differ significantly from the unconstrained best-fitting family ( $\chi^2_3 = 3.5$ ,  $p = .616$ ), exhibited excellent fit to the data, and explained 10.6% of the variance in competence satisfaction (see Model 5, Table 6).

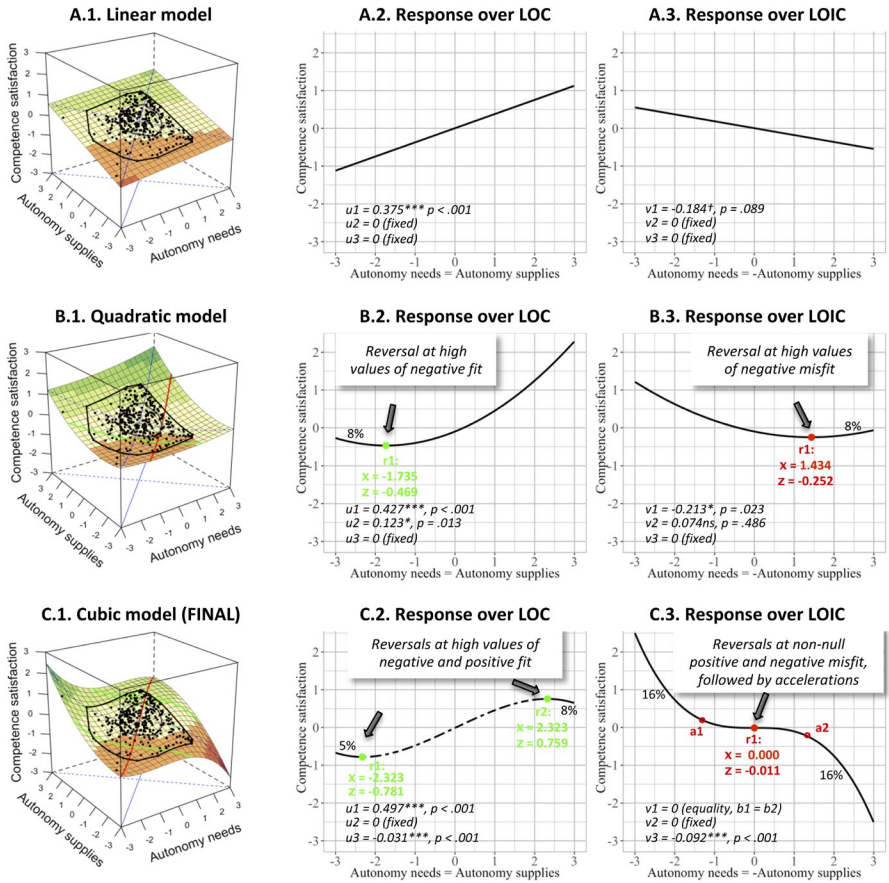
*Interpretation of the response surface.* The additive, linear model of competence satisfaction showed a positive response to variations in autonomy supplies and, tentatively, to autonomy needs ( $p = 0.102$ ). This model produced a response surface dominated by positive levels of fit compared to levels of misfit (Fig. 6A; see Model 5 Appendix B). These results provided some evidence of linear N-S fit and misfit processes.

In contrast, the quadratic model revealed marginally significant nonlinear effects ( $p = .111$ ) and two significant reversals (Fig. 6B; see Model 7 Appendix B). Along

**Table 6** Parameters of best-fitting polynomial models of competence satisfaction

Model	$b_1$	$b_2$	$b_3$	$b_4$	$b_5$	$b_6$	$b_7$	$b_8$	$b_9$
<i>Model 1: Best-fitting polynomial family FM36</i>									
Estimate	0.241	0.311	-0.073	0.027	0.073	-0.044	0.044	-0.044	-0.019
<i>p</i> value	.007	.017	.316	.507	.130	.034	.034	.034	.712
<i>Model 2: Best-fitting variant of FM36</i>									
Estimate	0.259	0.259	-0.078	0.000	0.078	-0.049	0.049	-0.049	0.000
<i>p</i> value	.000	.000	.033	fixed	.033	.000	.000	.000	fixed
<i>Model 3: Best-fitting variant of FM36, bootstrapped</i>									
Estimate	0.258	0.258	-0.087	0.000	0.087	-0.048	0.048	-0.048	0.000
CI 95%	(0.181, 0.350)	(0.181, 0.350)	(-0.183, 0.015)	fixed	(-0.015, 0.183)	(-0.084, -0.015)	(0.015, 0.084)	(-0.084, -0.015)	fixed
<i>Model 4: Best-fitting variant of FM36 with covariates</i>									
Estimate	0.222	0.222	-0.017	0.000	0.017	-0.026	0.026	-0.026	0
<i>p</i> value	.000	.000	.650	fixed	.650	.002	.002	.002	fixed
<i>Model 5: Best-fitting variant of FM36, MODIFIED</i>									
Estimate	0.249	0.249	0.000	0.000	0.000	-0.031	0.031	-0.031	0.000
<i>p</i> value	.000	.000	fixed	fixed	fixed	.000	.000	.000	fixed

$N=389$  students. Parameters  $b_1$  to  $b_9$  describe the cubic polynomial effects of needs ( $x$ ) and supplies ( $y$ ) in teacher autonomy support on competence satisfaction in a specific discipline ( $z$ ; language arts or mathematics). Covariates effects (i.e., age, gender, parental education level, general and course-specific grade point average) are reported in Table S4 (SM). Bootstrapped values correspond to means and 95% confidence intervals (1000 samples). Based on the robustness checks of the bootstrapped sampling and inclusion of covariates (Models 3 and 4), the “MODIFIED” model differs from the original best-fitting variant by fixing the quadratic effects of needs ( $b_3$ ) and supplies ( $b_5$ ) to zero



**Fig. 6** Response surfaces of alternative models of competence satisfaction. *Note* N=389 secondary school students. LOC=Line of congruence (N-S fit); LOIC=Line of incongruence (N-S misfit). Graphs show the response surface (column 1), response over the LOC (column 2), and response over the LOIC (column 3). Metaparameters  $u_1$  to  $v_3$  correspond to the linear, quadratic and cubic fit or misfit effects (see Appendix A). Green and red lines intersect reversal (“r”) and acceleration points (“a”) on the LOC and LOIC, respectively. Percentages reflect students significantly affected by reversals or accelerations. The fence represents the fourth quartile of the bagplot. Parameters for linear, quadratic, and cubic models are in Appendix B (Models 5 and 7) and Table 6 (Model 5)

the line of N-S fit (LOC axis; Fig. 6B.2), a reversal occurred at high levels of negative fit (*needs = supplies < -1.737*), where the negative effect of low needs and supplies diminished beyond this threshold (8% of students). Conversely, another reversal occurred at high levels of negative misfit (LOIC axis; Fig. 6B.3), indicating that the negative effect of deficient supplies diminished at extreme deficit equivalent to 3 SD (i.e., first reversal point occurring at *needs = -supplies = 1.434*, or a  $1.434 * 2 = 2.868$  SD deficit in supplies; 8% of students). However, neither the linear nor quadratic models provided a good overall fit to the data, limiting the reliability of their response surfaces.

The cubic model from the best-fitting variant (Fig. 6C; see Model 5, Table 6) demonstrated instead that these processes were in fact nonlinear and asymmetric, depending on the intensity of both positive and negative values of fit or misfit. For N-S fit (LOC axis; Fig. 6C.2), reversal effects were observed for students reporting similar amounts of needs and supplies approximately 2 SD below or above the mean (i.e.,  $needs = supplies < -2.323$  or  $> 2.323$ ). These represented extreme predictor values, though the reversals were contained within the bagplot of realistic data and concerned 5% and 8% of students, respectively. In contrast, for N-S misfit (LOIC axis; Fig. 6C.3), the nonlinearity manifested as a deceleration of the effects of positive and negative misfit around the minimax point centered at average predictor values (i.e., reversal point situated  $needs = -supplies = 0$ ), followed by accelerations beyond that point. More specifically, the effect of positive misfit (a relative excess in supplies) became increasingly beneficial for competence satisfaction as supplies grew excessive relative to needs, becoming substantial in size for a relative excess of 2.5 SD (i.e., first acceleration point situated at  $needs = -supplies = -1.345$ ; 16% of students). Conversely, the detrimental effect of negative misfit on competence satisfaction intensified with increasing deficits in supplies relative to needs for 16% of students (i.e., second acceleration point situated at  $needs = -supplies = 1.345$ ; Fig. 6C.3). This latter effect stood in stark contrast to the diminishing effect of negative misfit erroneously identified by the quadratic model (see Fig. 6B.3).

Because the interaction and quadratic effects were fixed to zero in the cubic model ( $b_3 = b_4 = b_5 = 0$ ; Model 5, Table 6), the curvatures along the LOC and the LOIC were null (i.e.,  $b_3 + b_4 + b_5 = 0$  and  $b_3 - b_4 + b_5 = 0$ , respectively; see Appendix A), thus preventing nonproportionality in fit or misfit processes. In other words, the reversal or acceleration of trends had equal intensity across high or low values of fit or misfit, a feature consistent with H11 (Fig. 4).

## 7 Discussion

This study introduces a novel approach to analyzing need satisfaction in SDT by examining the complex interplay between individual needs and contextual supplies of teacher autonomy support. Theoretically, it develops a phenomenology of needs-supplies fit emphasizing the significance of student differences in their needs for autonomy support, beyond contextual differences in the availability of such support. Methodologically, the study employed cubic RSA to identify symmetric or asymmetric nonlinearities in the relation between needs-supplies fit and need satisfaction at school. The findings emphasize the importance of individual differences in needs for teacher autonomy support, offering valuable insights for theory and practice in fostering self-determined behavior in educational settings.

## 7.1 Autonomy-supportive contexts depend on the level of student needs for autonomy support

The first contribution of this study is demonstrating that differences in students' needs for teacher autonomy support (i.e., what they regard as ideal levels of autonomy support for optimal learning) are critical for understanding processes of need satisfaction (RQ1). While previous SDT research focused on the relation between supplies in autonomy support (i.e., teacher's autonomy-supportive behavior as perceived by students) and need satisfaction, the present findings indicate that this relationship partly depends on the level of individual needs for autonomy support, as contended by research on person-environment fit (Choi, 2004; Edwards et al., 2006; Fraser & Rentoul, 1980; Gilbreath et al., 2011). These dependencies on needs levels in need satisfaction processes were nontrivial in effect size, being associated with increases of 30% in explained variance, as compared to a model only including the effects of supplies. Overall, this study provides a new understanding of autonomy-supportive contexts in SDT, demonstrating that feelings of autonomy or competence at school are linked to positive fit (i.e., high levels of both needs and supplies) and positive misfit (i.e., an excess of supplies relative to needs) (partial validation of H11 and H12).

At first glance, the conclusion that individual differences in needs influence need satisfaction processes may appear to contradict prior findings supporting the universality of basic psychological needs (Chen et al., 2015). This is not the case. Specifically, the question of universality relates to the independence of need satisfaction effects on behavior (e.g., well-being- from cultural variations in the endorsement of needs, such as variations in the perceived importance of satisfying needs (e.g., autonomy need strength) or the desire to change supplies to meet needs (e.g., autonomy need desire). Yet, the issue of needs-supplies fit processes differs, substantively, from the issue of personal endorsement of satisfying one's needs. Our study demonstrated that the level of teacher autonomy support needed to satisfy a student's need for autonomy or competence varies based on student perceptions of the optimal level of that support (i.e., perceived needs). However, this finding neither supports nor refutes the idea that all students benefit from attaining high levels of satisfaction in these needs, regardless of their personal endorsement of autonomy or competence (Chen et al., 2015).

In fact, complementary research (Núñez-Regueiro et al., 2024c) using the same methodology as this study confirmed that, consistent with SDT, positive fit and misfit in teacher autonomy support are linked to higher levels of subjective well-being, student engagement, and school achievement, whereas negative fit and misfit are linked to lower levels. The asymmetric N-S (mis)fit patterns found for these outcomes were very similar to those presently found for need satisfaction, suggesting that need satisfaction may mediate the process as expected from SDT (proposition Ib; Ryan & Deci, 2017). Therefore, the finding that student differences in needs matter in understanding needs-supportive contexts is fully compatible with the assumption that basic psychological needs are universal (Ryan & Deci, 2017).

## 7.2 Need satisfaction is nonlinearly related to positive needs-supplies fit or misfit

A second contribution of this study was demonstrating that the processes of N-S fit and misfit were strongly nonlinear for both autonomy and competence need satisfaction (RQ2). Nonlinear effects explained a significant portion of the variance in need satisfaction (12% to 18%), increasing the explained variance by 30% compared to a linear model. Specifically, this study identified cubic nonlinearities, illustrating how N-S fit or misfit could either benefit or harm need satisfaction depending on the degree of (mis)fit. A major original finding was the cubic nature of these nonlinearities, which impacted both positive and negative extremes—a notable departure from prior N-S fit studies that had only examined quadratic (single-sided) nonlinearities (Cable & Edwards, 2004; Choi, 2004; Edwards, 2002; Gilbreath et al., 2011).

Need satisfaction was negatively affected by excessive positive N-S fit (needs and supplies 1–2 SD above the mean), suggesting that students with very high autonomy needs might still feel unfulfilled despite high autonomy support. This ceiling effect resembles school burnout processes in academically intense contexts, where minimalist autonomy-supportive teaching (i.e., barely meeting student needs) might be experienced as emotionally exhausting to students (Bask & Salmela-Aro, 2013; Núñez-Regueiro, 2017). This suggests that some students—possibly with burnout symptoms—may benefit more from excess supplies (positive misfit) than from matching high supplies. Conversely, extreme negative fit (needs and supplies 2 SD below the mean) was linked to an adaptive floor effect, where students maintained need satisfaction despite low autonomy support—perhaps as a result of indifference stemming from boredom or helplessness (Buzzai et al., 2021; Núñez-Regueiro, 2017).

The study also found that varying degrees of N-S misfit affected need satisfaction differently. Moderate misfit (e.g., less than a 2/3 SD excess or deficit in supplies relative to needs) had minimal impact, whereas extreme positive misfit (3 SD surplus supplies) was related to high satisfaction, and extreme negative misfit (3 SD deficient supplies) to low satisfaction. For autonomy satisfaction, the pattern was nonproportional, with negative misfit reducing satisfaction more sharply than positive misfit increased it. These findings on N-S misfit suggest that, similar to the way physiological processes remain stable and adapt to mild caloric deficits or surpluses, need satisfaction responds minimally to small differences between students needs versus supplies in teacher autonomy support. However, as differences widen, the effects become more pronounced, with positive misfit becoming beneficial and negative misfit harmful.

The presence of the same family of cubic polynomials for both autonomy and competence satisfaction (i.e., level-dependent incongruent effect rotated by  $Y$ , FM36) should be considered with caution. While SDT research shows that teacher autonomy support strongly impacts both autonomy and competence satisfaction, suggesting a coherent underlying process (Ryan & Deci, 2020; Slemp et al., 2024), the nonlinearities in these processes differed. For instance, the acceleration of N-S misfit effects was non-proportional for autonomy satisfaction but proportional for competence satisfaction. Additionally, the reversal for positive N-S fit occurred at less extreme intensities for autonomy satisfaction (i.e., at +0.8 SD) compared to

competence satisfaction (+2.3 SD). Thus, while the findings indicate that similar polynomial families (i.e., FM36) are involved in need satisfaction processes, it is more accurate to conclude that N-S fit processes are nonlinear rather than linear. Indeed, nonlinearities can vary across polynomial families and samples.

### 7.3 The value of cubic response surface analysis for needs-supplies fit research

These results underscore the added value for needs-supplies fit research of a mixed confirmatory-exploratory paradigm based on cubic RSA (Núñez-Regueiro & Juhel, 2022a, 2024c; Schönbrodt, 2016), which compares alternative families of polynomial predefined by parametric constraints of the cubic function. This strategy is particularly effective because it enables the detection of complex nonlinearities (both symmetric and asymmetric) in needs-supplies fit processes that might otherwise be overlooked or underestimated. For instance, in the present study, a saturated polynomial approach would have suggested the nonsignificance for parameters associated with cubic nonlinearities (see Appendix B), despite clear evidence for such processes when predefined families were tested.

Similarly, the more traditional quadratic RSA was less effective in modeling the N-S fit processes, showing nonsignificant or only tendential effects, poorer fit, and explaining 20% to 35% less variance compared to the cubic polynomial families identified. In fact, in the present study, the quadratic RSA even produced misleading results, such as failing to detect a significant reversal process at high levels of N-S fit (see results on autonomy satisfaction, Fig. 5), or incorrectly suggesting a diminishing deleterious effect of extreme deficient supplies, when the better-fitting cubic solution revealed the opposite: an accelerating deleterious effect (see results on competence satisfaction, Fig. 6). These findings suggest that while quadratic RSA is widely used and may provide the best solution in some specific cases (e.g., Núñez-Regueiro & Wang, 2024; Núñez-Regueiro et al., 2024c), it may not fully capture the intricate dynamics of other processes like the present study, and may even produce spurious findings.

By adopting a comparative framework that considers both quadratic and cubic models, we were able to reveal nonlinear effects that the quadratic RSA missed or misidentified. More generally, future investigations of N-S fit processes are encouraged not to limit their analysis to quadratic RSA (risk of spurious findings), and to utilize instead a comparative approach to establish whether linear, quadratic, or cubic response surfaces provide the best representation of the data.

### 7.4 Limitations and research perspectives

The present study introduced several extensions and findings to SDT research, but these need to be interpreted with caution for different reasons. Methodologically, the sample was limited to a single context (French secondary education), was modest in size, and showed an overrepresentation of female students (albeit it was socially diversified). The latter overrepresentation might be problematic given that perceptions of autonomy supplies have been found to differ as a function of gender during

adolescence, notably across mathematics and language arts (e.g., Modrek et al., 2021). In the present study, the effect of gender was not significant, and the fact that N-S fit processes were investigated across these disciplines (i.e., language arts, mathematics) certainly minimized the influence of gender. Nevertheless, replication studies with more balanced samples from diversified contexts are needed to gauge the external validity of the present findings, but also to further test the psychometric soundness of the needs and supplies measures used. Moreover, the data were collected on a single occasion, which precluded analyzing how N-S fit and need satisfaction processes mutually influenced each other over time. This means the present evidence does not warrant causal inference, although the patterns of findings are coherent with causal processes assumed in SDT. Longitudinal data analyses of N-S fit effects on need satisfaction could offer a stronger basis for causal inference, but this would require methodological advances that integrate RSA and longitudinal data analysis techniques.

Theoretically, need satisfaction processes relate to perceptions of fit (molar approach), but do not directly relate to individual outcomes of N-S fit processes (see Fig. 1). Complementary research is therefore needed to understand whether the nonlinearities of N-S fit processes in need satisfaction processes also extend to individual outcomes (e.g., student engagement, achievement, subjective well-being). Relatedly, although teacher's autonomy support is known to fulfill all three psychological needs (including autonomy and competence, as the present study showed) as well as academic and developmental outcomes (Ryan & Deci, 2020; Slemp et al., 2024), N-S fit processes could be explored for alternative social ecologies with peers or parents, or for other basic psychological needs such as competence or relatedness. For example, using a similar measurement strategy for atomistic measures, one could investigate how student differences in the need for peer relatedness support (i.e., ideal amounts of relatedness) combine with supplies in peer relatedness support (i.e., actual amounts of relatedness) to predict relatedness satisfaction or subjective well-being (e.g., Núñez-Regueiro et al., 2024c). To gain a fuller understanding of N-S fit processes related to teachers, it would be beneficial to also consider teacher competence support (structure) (Aelterman et al., 2019). Our study focused on teacher autonomy support using a short-version of the Learning Climate Questionnaire (Jang et al., 2016; Williams & Deci, 1996). This choice allowed us to measure needs and supplies with just 10 items, keeping the survey concise and minimizing satisficing behavior from respondents (Galesic & Bosnjak, 2009). Future research could use a more comprehensive measurement system, such as the Situations-In-School Questionnaire (Aelterman et al., 2019; Vermote et al., 2020), to assess needs and supplies for both autonomy support and competence support.

## 7.5 Implications and conclusion

This research introduced an atomistic approach to analyzing need satisfaction in SDT, highlighting individual differences in needs for teacher autonomy support. This approach bridges two perspectives on needs, recognizing them as evolving "implicit motives" shaped by learning and experience (Fraser & Rentoul, 1980;

Hunt, 1975; McClelland, 1985), while also acknowledging the universal importance of need satisfaction for human growth (Deci & Ryan, 2000; Ryan & Deci, 2017). The study's key finding is that, although need satisfaction is universally crucial, the amount of support required varies among individuals based on their specific needs. This extension of SDT may help explain why moderate or high levels of support might satisfy some students but not others, due to variability in their psychological needs for support.

In practical terms, recognizing that students have varying needs for autonomy support means that teaching practices will be more effective when tailored to these individual needs. Some students may need only minimal support, while other may require more extensive support. This is significant because, while teachers often address diverse academic abilities in the class, they may not be aware of the varying needs for autonomy support among their students. In classrooms where teachers face multiple challenges (i.e., teaching stressors; Dicke et al., 2014; Klassen & Chiu, 2011; Núñez-Regueiro et al., 2024a), varying the level of autonomy support can help alleviate their burden by focusing on students who need it most. To implement these tailored practices, teachers must understand their students' specific needs. Interventions should help teachers adjust their levels of autonomy support to match students' needs, thereby enhancing satisfaction, engagement, and learning. For such tailored practice to be effective, teachers must first be in environments that support their own basic psychological needs (Ahn et al., 2021; Moè & Katz, 2022; Slemp et al., 2020). Therefore, achieving optimal needs-supplies fit for students also requires providing teachers with needs-supportive organizational contexts. More research is nevertheless needed to know whether teachers' need satisfaction processes also depend—as for students—on needs-supplies fit or misfit processes.

## Appendix A: Details on cubic polynomial modeling and hypotheses generation

The cubic polynomial model  $z = b_0 + b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 + b_6x^3 + b_7x^2y + b_8xy^2 + b_9y^3$  is composed of first-order ( $b_1$  to  $b_2$ ), second-order ( $b_3$  to  $b_5$ ), and third-order regression parameters ( $b_6$  to  $b_9$ ) which are responsible, respectively, for trends, curvatures and asymmetric curvatures in the response surface  $z$ . Through combinations of specific constraints across first-order to third-order polynomial parameters, this mathematical decomposition can generate over 2000 congruence hypotheses, grouped into families of polynomial models (37 families or FMs to date; for a list, see Núñez-Regueiro & Juhel, 2022, 2024c).

In this approach, the lines of congruence (LOC, *needs = supplies*) and incongruence (LOIC, *needs = -supplies*) have heuristic value for hypothesis generation, because substituting  $y$  by  $x$  values rewrites the cubic model twofold:

- 1)  $z(\text{LOC}) = b_0 + (b_1 + b_2)x + (b_3 + b_4 + b_5)x^2 + (b_6 + b_7 + b_8 + b_9)x^3$   
with metaparameters  $u_1 = b_1 + b_2, u_2 = b_3 + b_4 + b_5, u_3 = b_6 + b_7 + b_8 + b_9$ ;
- 2)  $z(\text{LOIC}) = b_0 + (b_1 - b_2)x + (b_3 - b_4 + b_5)x^2 + (b_6 - b_7 + b_8 - b_9)x^3$   
with metaparameters  $v_1 = b_1 - b_2, v_2 = b_3 - b_4 + b_5, v_3 = b_6 - b_7 + b_8 - b_9$ .

By imposing constraints on these two models, one can make precise hypotheses concerning the behavior of the outcome along the LOC and LOIC, which can then be combined to generate complex congruence hypotheses.

In this study, 12 congruence processes were conceived based on theoretical hypotheses about the combinatory effects of needs and supplies in teacher autonomy support on need satisfaction. The first kind of hypotheses (H1 through H4) shared the assumption that positive or negative needs-supplies fit did not lead to variations in need satisfaction, meaning the response surface should be horizontal along the LOC. To operationalize this horizontal LOC, hypotheses H1-H4 were built by selecting parametric constraints that cancelled out the linear effect (i.e.,  $b_1 + b_2 = 0$ ), the quadratic effect (i.e.,  $b_3 + b_4 + b_5 = 0$ ), and the cubic effect (i.e.,  $b_6 + b_7 + b_8 + b_9 = 0$ ) along the LOC [see equation for  $z(LOC)$ ]. At the same time, these constraints were chosen to reflect the positive linear effect (i.e.,  $b_1 - b_2 > 0$ ), the negative quadratic effect ( $b_3 - b_4 + b_5 < 0$ ), and the negative cubic effect ( $b_6 - b_7 + b_8 - b_9 = 0$ ) along the LOIC ([see equation for  $z(LOIC)$ ]). On this basis, we selected the polynomial families for hypotheses H1 to H4 that could accommodate both types of parametric constraints, notably the family of additive effects (FM3,  $-b_1 = b_2$ ), the family of congruence effects (FM7,  $b_3 = \frac{b_4}{-2} = b_5$ ,  $b_6 = \dots = b_9 = 0$ ; Edwards & Parry, 1993), and the family of asymmetric congruence effects (FM20,  $b_6 = \frac{b_7}{-3} = \frac{b_8}{3} = -b_9$ ; Humberg et al., 2022). Similar rationales were used to determine the constraints and the families of polynomials corresponding to the hypotheses of positive misfit (H5 through H8) and of positive fit or misfit (H9 through H12; see Table 2, main text).

Details on fundamental polynomials, rationales for their combination, a typology of complex congruence processes, and other illustrative examples, are available elsewhere (Núñez-Regueiro, 2024; Núñez-Regueiro & Juhel, 2022, 2024c, 2024d; Núñez-Regueiro & Wang, 2024; Núñez-Regueiro et al., 2024c).

## Appendix B Parameters of alternative polynomial models

Model	$b_1$	$b_2$	$b_3$	$b_4$	$b_5$	$b_6$	$b_7$	$b_8$	$b_9$
<i>Model 1: Linear (or additive) effects model for autonomy satisfaction</i>									
Estimates	-0.020	0.338	0	0	0	0	0	0	0
p values	.796	.000	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)
<i>Model 2: Interaction effect model for autonomy satisfaction</i>									
Estimates	-0.026	0.341	0	-0.021	0	0	0	0	0
p values	.742	.000	(fixed)	.595	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)
<i>Model 3: Saturated quadratic polynomial model for autonomy satisfaction</i>									
Estimates	-0.084	0.345	-0.073	0.008	0.049	0	0	0	0
p values	.395	.000	.096	.885	.359	(fixed)	(fixed)	(fixed)	(fixed)
<i>Model 4: Saturated cubic polynomial model for autonomy satisfaction</i>									
Estimates	0.106	0.433	-0.218	0.000	0.023	-0.062	0.061	-0.066	-0.069

Model	$b_1$	$b_2$	$b_3$	$b_4$	$b_5$	$b_6$	$b_7$	$b_8$	$b_9$
<i>p</i> values	.328	.000	.059	.999	.668	.075	.041	.345	.161
<i>Model 5: Linear (or additive) effects model for competence satisfaction</i>									
Estimates	0.096	0.279	0	0	0	0	0	0	0
<i>p</i> values	.102	.000	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)
<i>Model 6: Interaction effect model for competence satisfaction</i>									
Estimates	0.111	0.271	0	0.049	0	0	0	0	0
<i>p</i> values	.067	.000	(fixed)	.190	(fixed)	(fixed)	(fixed)	(fixed)	(fixed)
<i>Model 7: Saturated quadratic polynomial model for competence satisfaction</i>									
Estimates	0.107	0.320	0.021	0.024	0.078	0	0	0	0
<i>p</i> values	.103	.000	.633	.622	.111	(fixed)	(fixed)	(fixed)	(fixed)
<i>Model 8: Saturated cubic polynomial model for competence satisfaction</i>									
Estimates	0.243	0.310	-0.057	0.028	0.074	-0.038	0.049	-0.056	-0.021
<i>p</i> values	.016	.016	.461	.678	.138	.162	.143	.362	.712

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s11218-024-09959-3>.

**Author Contributions** Fernando Núñez-Regueiro: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing-Original Draft, Writing- Review and Editing, Visualization, Project administration Jacques Juhel: Conceptualization, Validation, Writing-Review and Editing. Ming-Te Wang: Conceptualization, Validation, Writing- Review and Editing.

**Funding** This research was partly supported by grants from the French National Research Agency in the frameworks of *Investissements d'avenir* (project "Make a Link!", ANR-15-IDEX-02).

## Declarations

**Conflict of interest** The authors report no conflict of interest.

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