SCANDINAVIAN JOURNAL OF EDUCATIONAL RESEARCH
https://doi.org/10.1080/00313831.2024.2348457

Routledge
Taylor & Francis Group

Autonomy need satisfaction and frustration during a learning session affect perceived value, interest, and vitality among higher education students

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ABSTRACT

In the current study, using self-determination theory as a theoretical framework, we used multiple real-time assessments to investigate the dichotomous relationship between autonomy need satisfaction and frustration, and how these constituents underpin student functioning among higher education students during a learning activity. In total, 124 STEM students were recruited from mandatory calculus seminars. The session lasted 90 minutes, with three fixed time measurements. Results indicate that satisfaction of the need for autonomy positively predicted vitality, situational interest, and perceived value, whereas autonomy need frustration was negatively related to the same outcome variables. Further, our results indicate fluctuations in both autonomy need satisfaction and need frustration during the calculus seminar. The results highlight well-differentiated effects of satisfaction and frustration of autonomy need and show that perceived need satisfaction and frustration constitute principal components in predicting student functioning.

ARTICLE HISTORY
Received 24 March 2023
Accepted 26 March 2024

KEYWORDS
Self-determination theory; autonomy satisfaction; autonomy frustration; vitality; interest; higher education

Introduction

According to self-determination theory (SDT; Ryan & Deci, 2017), experiencing autonomy is a pivotal constituent of feeling motivated and energized. SDT is a broad theoretical framework encompassing human growth, psychological well-being, and motivation, postulating that humans have a proactive propensity to experience growth, development, skill development, and feelings of volition (Guay, 2022). However, these proactive tendencies are not automatic; rather, they act as a function of social context, i.e., context can either foster or thwart these experiences (Ryan & Deci, 2017). Thus, according to SDT, the interaction between individual and social context delineates motivation.

Central to SDT is emphasizing that motivation is not a unitary construct; instead, it recognizes that humans experience different types of motivation (Deci & Ryan, 2008). For instance, a student can be motivated to complete homework because they are interested in the subject or see doing so as a means to procure good grades to please peers or parents. According to SDT, different types of motivation are distinguished depending on their level of self-determination (Ryan & Deci, 2017). At the most fundamental level, SDT distinguishes motivation as either *intrinsic*, whereby an activity is performed as a result of inherent interest and enjoyment, or *extrinsic*, whereby an activity is performed driven by pressure to do so (Núñez & León, 2016). However, SDT proposes that there are

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different types of extrinsic motivation depending on degree of experienced autonomy (Ryan & Deci, 2017). Ranging from impoverished to agentic, these states are amotivation (experiencing no meaning or sense of purpose when doing an activity), external regulation (driven by a desire for reward or to avoid punishment), introjected regulation (a response to an internal pressure such as guilt), identified regulation (the individual recognizes and identifies with the behavior or sees an activity as important), and integrated regulation (the activity is congruent with personal values). Thus, SDT categorizes motivation along a self-determined spectrum from amotivation, encompassing no experiences of self-endorsement, to intrinsic motivation, whereby the behavior is fully self-endorsed and driven by enjoyment and inherent interest (Cheon et al., 2018; Ryan & Deci, 2017). In educational settings, studies emphasize the importance of motivation as motivated students exert more effort in their assignments and exercises (Yeager et al., 2014), engage more with their peers and the learning content (Vansteenkiste et al., 2018), achieve better grades (Howard et al., 2021; Núñez & León, 2016), and experience more positive emotions during learning activities (Taylor et al., 2014).

Autonomy need satisfaction or frustration

Integral to basic psychological need theory (BPNT; Ryan & Deci, 2017), a sub-theory within SDT, is the notion that humans have a set of basic psychological needs and satisfying them is essential for development, motivation, and growth (Vansteenkiste et al., 2020). The need for autonomy is one of these fundamental psychological needs (Ryan & Deci, 2017). In an educational setting, the satisfaction of students' psychological need for autonomy can be determined by the interpersonal context in the classroom (Black & Deci, 2000). An instructor or teacher can support student autonomy by, for instance, incorporating students' perspectives into learning content and making it more relatable to everyday life (Kember et al., 2008; Terrón-López et al., 2017); acknowledging students' frame of reference and accepting negative emotions they could experience during learning activities (Reeve, 2009; Terrón-López et al., 2017); and allowing students time to ask questions and process the learning content (Reeve & Cheon, 2021). In line with the tenets of SDT, research indicates that autonomy need satisfaction relates to desirable outcomes such as academic engagement, achievement, fewer depressive symptoms among higher education students, a sense of well-being, and the promotion of autonomous forms of motivation, to name just a few (see, e.g., Canning & Harackiewicz, 2015; Cheon et al., 2018; Jiang & Tanaka, 2021; Núñez & León, 2015; Ryan & Deci, 2017; Zhou et al., 2019). The motivational path from autonomy to desired outcomes is referred to as the "bright" path.

Although need satisfaction is congruent with psychological thriving, growth, and well-being, recent research is emphasizes the "darker" motivational pathway arising from recognizing that autonomy satisfaction and autonomy frustration are two very different constructs with respective antecedents and outcomes (Bartholomew et al., 2011; Ryan & Deci, 2017; Warburton et al., 2020). In contrast to need satisfaction, need frustration is experienced when basic psychological needs are actively thwarted by a social agent and can be psychologically pathogenic (Vansteenkiste & Ryan, 2013), leading to insecurity and causing people to pursue extrinsic goals like fame, popularity, and materialism as an index of worth (Deci & Ryan, 2008). To illustrate the difference, a student may experience limited volition (i.e., low autonomy) during a learning activity and thus experience a decreased sense of well-being. But the student can also feel actively rejected by the teacher when offering comments or asking questions (i.e., need frustration), which can induce more severe symptoms of ill-being such as stress, psychopathology, or maladaptive behaviors (Vansteenkiste & Ryan, 2013). The relationship between need satisfaction and frustration is asymmetrical in nature; low need satisfaction does not necessarily entail need frustration whereas need frustration necessitates low need satisfaction (Bartholomew et al., 2011).

In line with distinguishing between need satisfaction and need frustration, SDT categorizes social context (e.g., the educational situation/classroom) as either need supportive or need

thwarting (Ryan & Deci, 2017). The social context can therefore either cordially foster someone's needs or be antagonistic towards them; that is, low need satisfaction represents a passive social context and need frustration actively impedes psychological needs (Mabbe et al., 2018). It is therefore important to investigate both these aspects to account for human functioning since one can experience need satisfaction and frustration within the same context (Vansteenkiste & Ryan, 2013).

According to SDT, there are two main consequences of frustrating psychological needs (Ryan & Deci, 2017). First, humans experiencing need frustration are prone to experience an immediate psychological cost, represented by greater ill-being (Mabbe et al., 2018; Stebbings et al., 2012). For instance, Joussemet et al. (2008) found that need-frustrating environments were linked to aggressive behaviors among elementary students. Further, studies have shown that students experiencing need frustration are more prone to being dishonest (Talwar & Lee, 2011) and experiencing depressive symptoms (Soenens et al., 2008). Second, when the meeting of psychological needs is actively frustrated, people are likely to develop maladaptive behaviors and coping strategies (Deci & Ryan, 2008; Vansteenkiste & Ryan, 2013). In an educational setting, a need-frustrating environment is associated with teachers using behaviors such as controlling language, neglecting students' perspectives and interpretations of the learning content, and being dismissive (Liu et al., 2017; Ryan & Deci, 2017). In line with the tenets of SDT, studies have shown that autonomy need frustration has been linked to less desirable outcomes such as lower student motivation and well-being (Liu et al., 2017; Warburton et al., 2020), lower social skills, and lower academic achievements (Buzzai et al., 2021; Cronin et al., 2019).

Autonomy satisfaction, frustration, and student functioning

From the SDT perspective, interest is crucial in terms of an individual's cognitive relationship to an object, activity, or idea; it provides the appeal desired at that specific moment (Deci, 1992). Research shows that interest supports a plethora of positive outcomes in learning, relating to persistence (Ainley et al., 2002), academic achievement (Harackiewicz et al., 2008; Köller et al., 2001), and student motivation (Bolkan & Griffin, 2018; Ryan et al., 2021). According to SDT, the process of developing interest is directly related to the satisfaction of basic psychological needs, whereas need frustration obstructs this development (Ryan et al., 2021). Among adolescent athletes, Reinboth et al. (2004) found that need satisfaction positively predicted interest in sports. Similarly, a cross-sectional study among primary students found that need satisfaction was positively related to interest (Zhou et al., 2019), a finding supported by Minnaert et al. (2007); Xiang et al. (2017), however, found no significant relationship between need satisfaction and interest.

When students experience satisfaction of the need for autonomy, they are more likely to experience feelings of vigor (Tsoi et al., 2018). Ryan and Frederick (1997) defined subjective vitality as an individual's awareness of experiencing being alive and feeling energized. Various studies have linked vitality among students to both physical and mental vigor (Núñez & León, 2016; Tsoi et al., 2018), in addition to academic achievement and resilience in relation to completing tasks and assignments (Garg & Sarkar, 2020). As emphasized by SDT, the satisfaction of basic psychological needs is a fundamental element of experiencing wellness (Ryan et al., 2021), and several studies have found a positive relationship between need satisfaction and student vitality (see, e.g., Black & Deci, 2000; Mouratidis et al., 2011). Taylor and Lonsdale (2010) found that satisfaction of the need for autonomy was linked to higher vitality among Chinese and British students, a finding also supported by Ommundsen et al. (2010). In higher education, a more recent study found that need satisfaction positively predicted vitality whereas need frustration was negatively related to vitality (Nishimura & Suzuki, 2016).

According to SDT, humans continuously refine their preferences and personal values while simultaneously finding conformity between them (Ryan, 1995; Vansteenkiste & Ryan, 2013). This unification is experienced as a sense of volition and autonomy. When autonomous, people's behavior is based on their personal values (Howard et al., 2021), and studies have shown that, when students

experience a sense of autonomy, they are more likely to integrate learning content in line with their own personal beliefs and values (Howard et al., 2021; Vansteenkiste et al., 2010). Helping students perceive some personal value in learning material has been demonstrated to increase motivation in higher education (Hulleman et al., 2010; Wagner et al., 2006) and boost academic achievement and performance (Rosenzweig et al., 2020). Instructors and teachers can, for instance, explain to students why learning activities are meaningful, both within the educational setting and outside of school, where applicable. Studies show that connecting learning content to everyday situations has beneficial learning outcomes (Canning & Harackiewicz, 2015; Waterschoot et al., 2019). Patall et al. (2013) found a positive relationship between satisfying the need for autonomy and value among high school students, a result supported in a similar study by Chen and Hypnar (2015).

Present study

The main aim of this study is to examine how autonomy need satisfaction and frustration relate to vitality, value, and interest in a higher education learning situation. Previous studies have identified relationships between satisfying the need for autonomy and outcomes such as vitality, value, and interest in educational settings (see, e.g., Howard et al., 2021; Núñez & León, 2016; Reinboth et al., 2004; Tsoi et al., 2018; Zhou et al., 2019); however, research on autonomy frustration is limited (see, e.g., Bartholomew et al., 2011; Liu et al., 2017; Nishimura & Suzuki, 2016; Vansteenkiste & Ryan, 2013). Further, despite the current body of research on these relationships, to what extent these findings can be generalized to a situational level and within-subject functioning level remains unexplored. Thus, a secondary aim of this study is to investigate intra-individual fluctuations in perceived autonomy satisfaction and frustration during a learning situation. A main advantage to using a within-subject approach compared to a cross-sectional design is that it is less likely that detected effects will be construed by individual variance between situations (Charness et al., 2012). Specifically, the current study employs an experience sampling method (ESM) to investigate how autonomy satisfaction and frustration relate to motivation (interest), growth (perceived value), and well-being (vitality), and whether levels of autonomy satisfaction and frustration vary over time for individual students.

This intense longitudinal design allows the situational data to be nested within students. Analyzing these data using linear mixed-effects models enables the investigation of (1) whether autonomy need satisfaction or frustration predict interest, value, and vitality, and (2) intra-individual fluctuations in autonomy need satisfaction and frustration. In line with previous studies (see, e.g., Mouratidis et al., 2011; Nishimura & Suzuki, 2016; Patall et al., 2013; Ryan et al., 2021; Vansteenkiste & Ryan, 2013; Zhou et al., 2019), we test whether (H1) autonomy need satisfaction positively predicts vitality, value, and interest, while need frustration negatively predicts the same variables. Further, based on previous research on intra-individual daily fluctuations in need satisfaction and frustration (e.g., Mabbe et al., 2018; Ryan et al., 2010), we test whether (H2) need satisfaction and frustration demonstrate intra-individual variations during the learning session.

Materials and methods

Participants

The participants consisted of 124 first-semester undergraduate STEM students from a Norwegian university (46% female, 54% male; none reported "other" or "would rather not disclose"). To protect anonymity, age was recorded in year ranges (18–19 [65%], 20–21 [26%] and, > 21 years [9%]).

Procedure

The students were recruited during mandatory introductory calculus course seminars for first-semester STEM students. Students enrolled in this course were assigned to one of 25 seminar

groups, consisting of 15–25 students in each group. Different seminar groups had different time schedules throughout the week so that students could sign up to a seminar that did not clash with other courses or lectures. During these seminars, the students worked on exercises and assignments and a teaching assistant was present to offer guidance and assistance. The seminars were divided into two 45-minute sessions, each with a 15-minute break. The study was conducted halfway through the semester to ensure that the students were familiar with both the content of the course and the seminars from which they were recruited. The students were asked to participate in the study at the beginning of the seminar, and those who did so were given a hardcopy handout of the questionnaires and were told to work on their assignments as usual until they were notified to complete them. The students had to complete the questionnaires following a strict schedule; that is, at 10 minutes, 40 minutes, and 90 minutes after the beginning of the seminar. The students had no knowledge of this schedule. Of the 131 students asked to participate, seven had scheduling conflicts with other courses that prevented them from completing the survey and they were thus not included.

Participation was voluntary and no reward was offered. The students were told about the study at the start of the seminars and informed that they could withdraw at any time, that it was anonymous, and that data would be treated confidentially. This study was reviewed and approved by the System for Risk and Compliance: Processing of Personal Data in Research (RETTE).

Measures

For the current ESM study, we opted to use single-item measures to reduce participant burden as well as capture their immediate experiences in a natural learning setting (Fisher et al., 2016; van Hooff et al., 2007). The items were selected based on psychometric properties from validity studies.

Interest/enjoyment

To measure interest, we used an item from the Interest/Enjoyment sub-scale from the Intrinsic Motivation Inventory scale (Deci et al., 1994). Previous studies have found the scale to be reliable (Deci et al., 1994; Tsigilis & Theodosiou, 2003). Based on the results from a recent validity study in an educational setting (Ostrow & Heffernan, 2018), we used the highest exploratory factor analysis (EFA) scoring item (.879) from this scale (#2: "This activity was fun to do") and asked the students to rank this statement on a seven-point Likert scale, ranging from 1 (not true at all) to 7 (very true).

Vitality

To measure vitality, we used an item from the Subjective Vitality Scales (Ryan & Frederick, 1997). Previous studies have found the Subjective Vitality Scales to be reliable (Bertrams et al., 2020; Bostic et al., 2000; Salama-Younes et al., 2009). Based on the strongest path coefficient (12.63) from a structural equation model (SEM) analysis in a previous validity study used in higher education (Bostic et al., 2000), we used item #1 from this scale ("I feel alive and vital") and asked the students to rank this item on a seven-point Likert scale, ranging from 1 (not true at all) to 7 (very true).

Autonomy need satisfaction and frustration

To measure autonomy need satisfaction and frustration, we used two items from a sub-scale of the Basic Psychological Need Satisfaction and Frustration Scale, the BPNSFS Diary measures (Chen et al., 2015). Based on previous validity studies using the strongest standardized pathway coefficients from a SEM analysis (Chen et al., 2015; Liga et al., 2018), we used item #1 for autonomy satisfaction (.81; "I felt a sense of choice and freedom in the things I did") and item #4 for autonomy frustration (.80; "most of the things I did felt like 'I had to'"). Students were asked to rank these statements on a seven-point Likert scale ranging from 1 (not true at all) to 7 (very true).

Value

To measure perceived value, we used an item from the Value/Usefulness sub-scale from the Intrinsic Motivation Inventory scale (Deci et al., 1994). Previous studies have found reliable results for this scale in higher education (Tsigilis & Theodosiou, 2003). Based on a previous validity study (McAuley et al., 1987), we used item #1 from this scale ("I believe this activity could be of some value to me"). The students were asked to rank this statement on a seven-point Likert scale ranging from 1 (not true at all) to 7 (very true).

Control variables

We included control items to investigate factors that could impact students' current experiences. Students had to identify whether they were (1) working on assignments, (2) using a smartphone or laptop for activities not related to the seminar, (3) having to pay attention because the seminar leader was speaking/lecturing, or (4) they were doing anything else not covered by the other control questions immediately before responding to the questionnaires.

Statistical analysis

All statistical analyses were performed using the open-source program, R version 4.2.1 (RStudio, 2022). We used a linear mixed-effects model approach to examine if autonomy need satisfaction and frustration predicted vitality, value, and interest, using the lmer package, version 1.1-30 for R (lmer, 2022). The data were structured at two levels: between-student and within-student. We tested six main regression models (autonomy need satisfaction/frustration → vitality/interest/value), and for each main model we tested three different effect models. First, a between-level linear regression model, e.g., in the case of autonomy need satisfaction (AS) predicting vitality (VIT):

$$AS = \beta_0 + \beta_1 \times VIT + \varepsilon, \tag{1}$$

where β_0 and β_1 denotes intercept and effect, respectively. Second, we tested a mixed-effects model with fixed effects and random intercepts, e.g.,

$$AS = \beta_{int_{student}} + \beta_1 \times VIT + \varepsilon, \tag{2}$$

with

$$\beta_{int_{student}} = \beta_0 + \beta_{0_{student}} \tag{3}$$

where $\beta_{0_{student}}$ denotes the random intercept for each individual student. Finally, we tested a random intercept and random effects model, e.g.,

$$AS = \beta_{int_{student}} + \beta_{eff_{student}} \times VIT + \varepsilon, \tag{4}$$

where

$$\beta_{int_{student}} = \beta_0 + \beta_{0_{student}}, \quad \beta_{eff_{student}} = \beta_1 + \beta_{1_{student}} \tag{5}$$

in which we included the term $\beta_{1_{student}}$ denoting the random effect for each individual student. Intra-individual fluctuations were assessed based on intraclass correlation coefficients (ICC). Preferred model selections were based on the lowest scores of the Akaike information criterion (AIC) and Bayesian information criterion (BIC).

Results

In general, the inter-individual (between-level) correlations were weaker relative to the intra-individual (within-level) correlations. All bivariate correlations were as hypothesized. Table 1 presents

Table 1. Means and standard deviations for study variables.

Variable	M	SD	Min	Max	Range
Autonomy satisfaction	4.48	1.44	1	7	6
Autonomy frustration	5.20	1.27	1	7	6
Vitality	4.29	1.47	1	7	6
Value	4.63	1.02	2	7	5
Interest	4.09	1.62	1	7	6

Note: All items were scored on a scale from 1 (not true at all) to 7 (very true). The means are averaged across all students and item responses.

the means and standard deviations for all variables. Table 2 shows the bivariate correlations between the study variables at both levels (within-student and between-student).

According to almost every measurement (>95%), the students replied to the control question that they were working on the assignments at the time, implying that the effects were not a function of the other control variables.

Table 3 presents an overview of the regression coefficients for the various model approaches. The results suggest that autonomy need satisfaction positively predicts vitality at both the within-level ($\beta_1 = .57$) and the between-level ($\beta_1 = .61$). Further, our results indicate that autonomy need satisfaction predicts interest more strongly at the between-level ($\beta_1 = .49$) compared to the within-level ($\beta_1 = .30$). The random effects correlation ($r = -.74$) indicates that students starting the session experiencing a high degree of vitality are also susceptible to larger changes in vitality as changes in experienced autonomy need satisfaction occur. Our results further indicate that autonomy need satisfaction weakly predicts value both at the within-level ($\beta_1 = .15$) and the between-level ($\beta_1 = .20$), again with a moderate-to-strong random effects correlation ($r = -.69$). Next, our results suggest that autonomy need frustration negatively predicts vitality at both the within-level ($\beta_1 = -.37$) and the between-level ($\beta_1 = -.43$), with a strong random effects correlation ($r = -.85$). Further, our findings indicate that autonomy need frustration negatively predicts interest at both the within-level ($\beta_1 = -.16$) and the between-level ($\beta_1 = -.14$); it also negatively weakly predicts value at both the within-level ($\beta_1 = -.12$) and the between-level ($\beta_1 = -.10$). The random effects correlation ($r = -.53$) suggests that students beginning the session showing interest in the learning material are moderately affected by autonomy need frustration over time.

Of all models, two had singular fits (i.e., at least one dimension of the variance–covariance matrix converged to zero, thus implying overfitting): the random intercept and random effects models for autonomy need satisfaction predicting vitality, and the random intercept and random effects model for autonomy need frustration predicting value. Across all models, omitting the two models with singular fits, linear mixed-effects models with random intercepts and fixed effects were marginally better based on AIC and BIC (Table 3). Further, Table 3 presents an

Table 2. Within- and between-person correlations of study variables.

Variable	1	2	3	4	5
L1: Within level					
1 Autonomy satisfaction	1				
2 Autonomy frustration	−.54	1			
3 Interest	.50	−.09	1		
4 Vitality	.62	−.43	.58	1	
5 Value	.36	−.17	.41	.45	1
L2: Between level					
1 Autonomy satisfaction	1				
2 Autonomy frustration	−.22	1			
3 Interest	.27	−.19	1		
4 Vitality	.39	−.27	.30	1	
5 Value	.14	−.12	.17	.18	1

Note: All are significant at a p-level of $< .05$.

Table 3. Overview of coefficients (β), ICC, AIC, and BIC for the three different model approaches to each regression model (linear model, linear model with random intercept and fixed effects, and linear model with random intercept and random effects). Correlation coefficients between random effects and random intercepts are given by r.

Model	β_0	β_1	ICC	AIC	BIC	r
AS → VIT						
Linear model	1.55	.61		1178.3	1190.1	
Random intercept and fixed slope		.57	.23	1172.2	1187.8	
Random intercept and random slope	↟	–	–	–	–	–
AS → INT						
Linear model	1.88	.49		1339.5	1351.3	
Random intercept and fixed slope		.30	.70	1169.6	1185.3	
Random intercept and random slope			.80	1170.9	1194.4	−.74
AS → VAL						
Linear model	3.71	.20		1039.6	1051.4	
Random intercept and fixed slope		.15	.52	958.9	974.5	
Random intercept and random slope			.67	961.8	985.3	−.69
AF → VIT						
Linear model	6.50	−.43		1290.5	1302.3	
Random intercept and fixed slope		−.37	.38	1251.3	1266.9	
Random intercept and random slope			.40	1253.3	1276.8	−.85
AF → INT						
Linear model	4.85	−.14		1413.6	1425.4	
Random intercept, fixed slope		−.16	.67	1201.1	1216.7	
Random intercept and random slope			.79	1203.1	1226.6	−.53
AF → VAL						
Linear model	5.24	−.12		1064.4	1076.1	
Random intercept and fixed slope		−.10	.55	969.8	985.5	
Random intercept and random slope	↟	–	–	–	–	–

Note: AS = autonomy satisfaction; AF = autonomy frustration; VIT = vitality; INT = interest; VAL = value; ↟ = singular fits.

overview of the intraclass correlation coefficients that express the percentage that is left from the total variance and thus explained by intra-individual fluctuations during the seminar. Findings indicate that 23–80% of the variances could be explained by intra-individual differences. Particularly large were the ICCs for autonomy need satisfaction and frustration predicting interest. Figure 1 depicts autonomy need satisfaction and frustration as a function of the three time measurements for 10 random participating students.

Discussion

Our main goal was to investigate how university students' autonomy need satisfaction and frustration relate to interest, value, and vitality during a calculus seminar. In line with theoretical propositions derived from SDT, the results supported our hypotheses.

Satisfaction of students' need for autonomy positively predicted vitality at both within- and between-levels. When vital, humans experience a sense of vigor, aliveness, and energy (Kocayoruk, 2012). Since efforts to control one's own behavior are considered psychologically depleting, whereas vitality is associated with a surplus of energy and vigor, SDT postulates that the satisfaction of basic psychological needs maintain and enhance vitality (Ryan & Deci, 2008). More specifically, SDT proposes that students engaging in learning activities that satisfy the basic need for autonomy positively predicts vitality (Ryan & Deci, 2008). Similar results have been found among adolescent students (see, e.g., González-Cutre & Sicilia, 2019; Mouratidis et al., 2011; Taylor & Lonsdale, 2010). In a higher education setting, our findings mirror the results of a study by Levesque et al. (2004) conducted in four German and American universities. After controlling for invariance across countries and testing a full SEM model, Levesque et al. (2004) found that vitality was positively predicted by experiences of autonomy. Further, comparable findings have also been reported in non-educational contexts, such as in non-academic staff at a British university relating to physical exercise (Kinnafick et al., 2014) and among athletes (Adie et al., 2008). Contrary to our findings, a recent

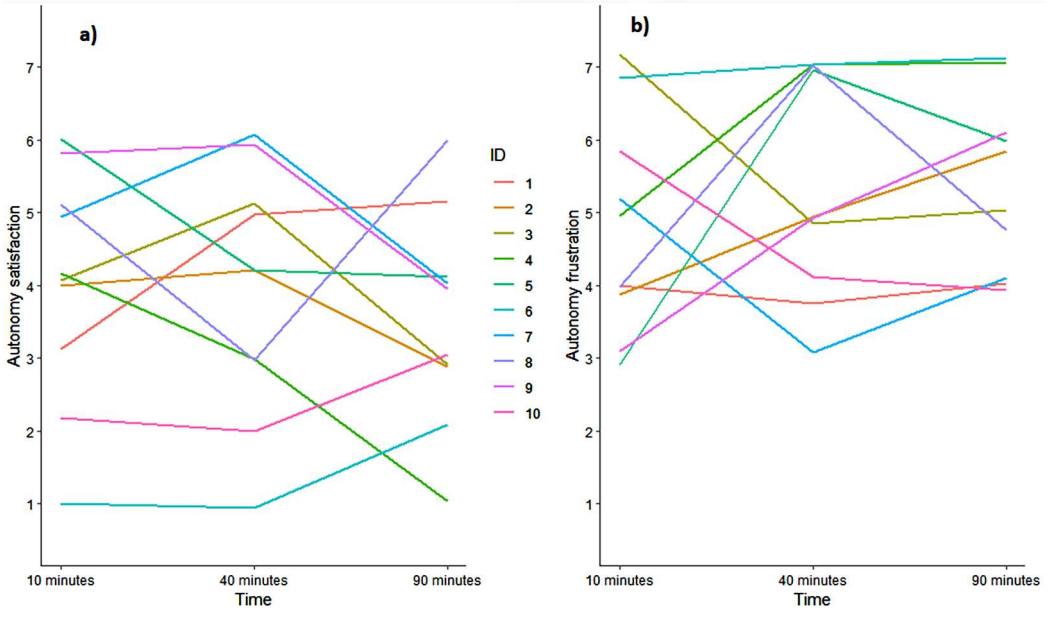

Figure 1. Autonomy satisfaction (a) and frustration (b) as a function of the three time measurements ($T_1 = 10$ minutes, $T_2 = 40$ minutes, and $T_3 = 90$ minutes) for 10 random students in the study.

Note: ID corresponds to individual students.

study among higher education students found no significant relationship between autonomy need satisfaction and vitality, but vitality was predicted by need satisfaction if mediated by autonomous motivation (Martinek et al., 2021).

Next, we found that autonomy need frustration negatively predicted vitality at both within- and between-levels. This result is in line with Liu et al.'s (2017) study on adolescent students, whereas no relationship was found in similar studies among secondary school pupils (Earl et al., 2017) and non-academic adolescents (Costa et al., 2016). In a study by Tsoi et al. (2018) on 425 Dutch pharmacists enrolled in post-academic pharmacy education courses, autonomy need frustration was also found to be negatively related to vitality (unstandardized $\beta = -1.61$) using SEM analysis. Liu et al.'s (2017) SEM analysis indicated that, albeit autonomy need satisfaction positively predicted vitality (standardized $\beta = .80$), only a weak relationship existed between autonomy need frustration and vitality (standardized $\beta = -.16$). Vitality is a subjective state, but it is also multi-determined beyond the educational setting (Martela et al., 2016; Ryan & Deci, 2008). Vitality can be influenced by somatic factors such as sleep deprivation, diet, and exercise, and social factors stretching beyond the scope of the classroom (Ryan & Deci, 2008). Thus, subjective vitality is a trait rather than a subject matter relevant to the course, and interpretations of these results should therefore be more nuanced. This is also reflected in the low ICC for the mixed-effects model for autonomy need satisfaction predicting vitality, indicating that a low percentage of the within-student variance accounts for total variance. In other words, intra-individual fluctuations in vitality do not appear to be mainly controlled by the context (the seminar), and thus are regulated by features outside the educational setting. Further, the high random effects correlation suggests that students beginning the seminar with higher vitality are more affected by autonomy need frustration, whereas if they initially experience low vitality, they are less affected by need frustration. This result is expected since vitality is associated with experiencing a surplus of energy and vigor (ibid.). Vitality as a psychological construct is a trait of experiencing well-being. However, this study did not include any measurements for *ill-being*. We therefore recommend that future researchers include this aspect in addition to mapping an even more comprehensive picture of psychological functioning.

Consistent with our hypothesis, we found that autonomy need satisfaction positively predicted interest at both within- and between-levels. These results are supported by a recent study by Leisterer and Gramlich (2021). Further, similar results were found by Wang et al. (2019), Mouratidis et al. (2011), and Minnaert et al. (2007) among secondary school students. According to SDT, developing interest in an activity is directly related to the satisfaction of someone's basic psychological needs (Ryan et al., 2021). In contrast, the frustration of needs obstructs this development. Our study supports this claim; that is, we found that autonomy need frustration negatively predicted interest. However, this contradicts the results of a recent study by Cuevas-Campos et al. (2020) among adolescent students in which they found no significant relationship between variables. Further, random effect correlations indicate that students showing high initial interest in the learning session were strongly influenced by autonomy need satisfaction, and moderately affected by autonomy need frustration. This implies that students who experience low initial interest are less impacted by autonomy need satisfaction. However, this also highlights the detrimental effect of need frustration as it has a stronger impact on interest relative to need satisfaction when showing initial low interest, thus echoing the importance of making learning content more interesting and relevant for students (Vansteenkiste et al., 2018).

Next, in line with our hypothesis, we found that autonomy need satisfaction positively predicted value. This result is similar to that of a study in higher education by González and Paoloni (2015), as well as studies by Rosenzweig et al. (2019) and Patall et al. (2013) conducted among high school students. Next, in line with our hypothesis, we also found that autonomy need frustration negatively predicted value. This is expected because the experience of refining personal values and preferences over time while finding conformity between them is the antecedent of autonomy (Vansteenkiste & Ryan, 2013). Further, the random effect correlations indicate that students who started the seminar with a high perceived value of the learning content are more affected by autonomy need satisfaction relative to students who experience lower degrees of perceived value. Rooted in SDT, this can be explained by the fact that the sense of autonomy is a product of experiencing growth, development, and change in personal values while finding conformity between them (ibid.). Thus, one's personal values are directly linked to one's sense of autonomy; the higher one values an activity, the more impacted this perceived value would be by the sense of volition.

Finally, in line with our hypotheses (H2), we detected intra-individual fluctuations (Table 3). The smallest ICCs were related to vitality (as discussed above). Notably, we found large intra-individual fluctuations in interest (67–80%), which could indicate that perceived interest among students is highly regulated by educational context (seminar activities). According to SDT, interest is an explicated self-determined response to an activity that provides a sense of novelty, challenge, or response to another factor one desires at a given time (Deci, 1992), and hence one would expect to observe fluctuations in this measure as the seminar encompasses different and varied exercises throughout the learning session. Notably, referring to Figure 1, we can observe fluctuations in both autonomy need satisfaction and frustration over the course of the seminar for 10 random students, a finding supported by previous studies (see, e.g., Ketonen et al., 2018; Mabbe et al., 2018; Ryan et al., 2010) . Interestingly, for the current study, we opted to include control questions to control for the situational contexts (whether students were working on assignments, using smartphones, etc.). However, for almost every measurement students responded that they were working on their assignments and exercises, implying that the observed effects were all a function of autonomy need satisfaction (or frustration) and not of other control variables.

Limitations and future research

Several limitations are worth mentioning when interpreting the results of our study. First, we used single-item measurements. Albeit they lessen the burden on participating students and are preferred in ESM studies due to their ability to capture immediate experiences (avoiding memory bias), multiple-item measures have better psychometric properties (Fisher et al., 2016; van Hooff

et al., 2007). To complement the results of the current study, future research could use multiple-item measurements in similar studies. Further, the study period was one day only. Future researchers are encouraged to implement a more extensive longitudinal design to add another level to the data, which would, for instance, enable researchers to compare intra-individual variations on both a situational and a day level.

According to Ahmadi et al. (2023), facilitating learning conditions in which students are allowed to direct the learning activity themselves can have a profound impact on motivation. With this in mind, for instance, a similar study could be conducted but allowing for half of the seminars to be "self-directed" by the students; following this, model invariance could then be checked for. Another possible behavioral intervention is providing rationale (Canning & Harackiewicz, 2015). Calculus is very abstract in nature with little to no real-life tangibility, thus an intervention whereby one group of students receive the regular curriculum whereas the other group are provided *rationales* in their assignments, i.e., exercises anchored in real-life problems, could be an interesting study. Another behavioral intervention study could be grounded in *autonomy supportive language*, whereby the teaching assistants in one group use autonomy-supportive language whereas the teaching assistants in the other group rely strictly on controlling language when helping students. All these behavioral interventions could potentially impact the models presented in this study; however, they could also potentially influence the intra-individual experiences of autonomy need satisfaction and thwarting.

Conclusion

Overall, the current study makes an important contribution to the field of SDT by including *need frustration* as a part of human functioning in a severely barren field of literature in studies concerning higher education. Detecting need satisfaction is imperative as it not only fosters student motivation and academic achievement but also affects students' psychological health, development, and sense of well-being. However, arguably as important is detecting need frustration as it can be accompanied by a plethora of unwanted outcomes, both in an educational setting and out-of-school contexts. Furthermore, the fluctuations in need satisfaction and frustration during the learning session strongly suggest that the characteristics of the educational setting can have an influence on students. As such, every learning situation matters, and the educational context should thus be aimed at both nurturing basic needs and avoiding frustrating them.

Disclosure statement

No potential conflict of interest was reported by the authors.

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