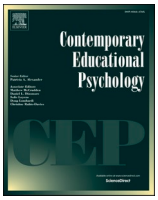
Contemporary Educational Psychology 71 (2022) 102095

Contents lists available at ScienceDirect

Contemporary Educational Psychology

journal homepage: www.elsevier.com/locate/cedpsych



How are learning experiences and task properties associated with adolescents' emotions and psychophysiological states?

Noona Kiuru [a,*], Lars-Erik Malmberg [b], Kenneth Eklund [c], Markku Penttonen [a], Timo Ahonen [a], Riikka Hirvonen [d]

[a] Department of Psychology, University of Jyvaskyla, Finland
[b] Oxford University, University of Jyväskylä, Finland
[c] Faculty of Education and Psychology, University of Jyväskylä, Finland
[d] University of Eastern Finland

ARTICLE INFO

Keywords:
Adolescence
Experienced emotions
Psychophysiological states
Value of success, level of challenge, mastery experience

ABSTRACT

We examined whether learning experiences (value of success, mastery experience) and task properties (challenge) are related to early adolescents' ($n = 190$, median age = 12) emotional responses and psychophysiological states (autonomic nervous system, ANS) in achievement situations in an ambulatory laboratory. They completed four achievement tasks (two math and two reading) at different challenge levels in randomized order, and reported their learning and task perceptions for each task. The proportion of errors indicated the objective demandingness of each task. As indices of sympathetic nervous system activity, we recorded skin conductance response (SCR) and heart rate (HR), and, as parasympathetic nervous system activity, their heart rate variability (HRV). Following control-value and flow theories, we proposed hypotheses for main and interaction effects and specified multilevel models (tasks nested in persons). Novel findings emerged. Aside from the anticipated main effects, Challenge × Mastery interaction also was related to adolescents' emotions and SCR at the within-person (task) level. Furthermore, Value × Mastery Experience interaction was related to SCR and HRV at the task level, whereas Value × Errors interaction contributed to experienced anger and anxiety at the between-person (individual) level. The findings provide novel understanding of situational interplay between the value of success, challenge, and mastery experience in adolescents' experienced emotions and psychophysiological states.

1. Introduction

Emotions are responses to personally meaningful situations that change the quality of an individual's feelings, expressive behaviors, and physiological activation (Kreibig, 2010; Levenson, 2014; Mauss & Robinson, 2009). Achievement emotions refer to emotions that are directly linked to achievement activities or achievement outcomes (Pekrun, 2006; Pekrun et al., 2002), and they are strongly associated with learning, achievement, and psychological health (for a review, see Pekrun, 2017). Thus, understanding which kinds of learning experiences can predict achievement emotions and related physiological reactions and states is an important area of research with potential implications for learning and adaptive academic functioning, and for a deepened understanding of how "mind" and "body" are linked in learning contexts.

Value of success and subjective control over achievement activities and their outcomes have been suggested to play a central role in the emotions experienced in learning (Pekrun, 2006, 2017). Previous studies conducted at the between-person level have consistently shown that high control and high value contribute to higher levels of positive achievement emotions, such as hope, enjoyment and pride (e.g., Boekaerts, 2001; Frentzel et al., 2007; Pekrun, 2017). High control has also been consistently found to relate to lower levels of negative emotions, such as anger and anxiety (e.g., Clem et al., 2021; Linnenbrink & Pintrich, 2002; Pekrun 2017). However, we cannot generalize findings from between-person studies to within-person functioning (Molenaar & Campbell, 2009; Nesselroade & Molenaar, 2016). By contrast, a within-person approach can capture dynamic variations within individuals across situations, thus allowing us to examine whether individuals experience certain emotions in response to certain situational factors (i.e., within-person effects; see also Bieg et al., 2013; Voelke et al., 2014). Although an increasing number of studies investigating achievement

* Corresponding author at: Department of Psychology, University of Jyväskylä, P.O. Box 35, 40014 Jyväskylä, Finland.
E-mail address: noona.h.kiuru@jyu.fi (N. Kiuru).

https://doi.org/10.1016/j.cedpsych.2022.102095

Available online 11 August 2022

emotions use an intraindividual approach and real-time assessments (e.g., Goetz et al., 2010; Ketonen et al., 2019; Tanaka & Murayama, 2014), the empirical evidence on intraindividual antecedents of adolescents' emotions and related psychophysiological states remains limited.

In order to expand previous studies, our multilevel study focused on both intraindividual and interindividual variation in the role of learning experiences (success value, mastery experience) and task properties (challenge) in adolescents' distinct emotions (i.e., hope, enjoyment, anger, anxiety, fear, hopelessness) and physiological reactions of the autonomous nervous system during simulated achievement situations. As indices of sympathetic nervous system activity, we recorded adolescents' skin conductance response (SCR) and heart rate (HR), and as parasympathetic nervous system activity their heart rate variability (HRV). To the best of our knowledge, our study is among the first situational studies to investigate the role of both learning experiences and task properties (level of difficulty or challenge) in adolescents' achievement emotions and psychophysiological states.

2. Emotions and psychophysiological states in achievement situations

Students frequently experience various emotions at school (Pekrun et al., 2002). These emotional responses are structured along two dimensions/axes: valence (pleasure vs displeasure) and arousal (activation vs de-activation) (Barrett., 2006; Levenson, 2014; Russell, 1980). Positive activating emotions (e.g., enjoyment of learning) that are related to higher interest, effort, and elaboration of learning material, have consistently been shown to promote performance. Deactivating negative emotions (e.g., hopelessness, boredom) that are related to higher task-avoidance, lower task-focus and lower concentration have consistently been shown to undermine achievement (for reviews, see Pekrun 2006, 2017). Moreover, positive deactivating emotions unrelated to the task at hand, such as fantasizing about spending time with friends or romantic partners, may be enjoyable, but can detract attention from learning (see also Pekrun, 2017). The underlying mechanisms of negative activating emotions may be more complex and related empirical results are mixed. For example, anxiety, fear and frustration have been shown to trigger task-irrelevant thinking in some situations, which reduces the cognitive resources available for task concentration (see Pekrun, 2006). However, slightly heightened levels of negative activating emotions may also sometimes induce the motivation to study harder and facilitate learning (Pekrun, Goetz, Titz, & Perry, 2002).

Emotions and emotion regulation can also be observed in the activation of the autonomic nervous system, which regulates a wide range of bodily functions, such as blood pressure and body temperature (Kreibig & Gendolla, 2014). The ANS is divided into an excitatory sympathetic nervous system (SNS) and an inhibitory parasympathetic nervous system (PNS) that interact to produce physiological reactions in emotional situations (Berntson et al., 1991). During physical or psychological stress, the activity of the SNS aids the body to adapt to a challenge. It is noticeable as increased heart rate (HR) and increased skin conductance response (SCR; changes in the electrical conductance of the skin depending on sweat gland activity and the resulting quantity of sweat; Boucsein, 2012; Posada-Quintero & Chon, 2020). During periods of safety and calmness, the PNS decreases the heart rate and increases heart rate variability (HRV; Beauchaine, 2001; Crowell et al., 2014; Porges, 2007). HRV describes variation in the time interval between heartbeats and reflects how much cardiac activity is modulated to meet changing situational demands (Berntson et al., 1997). HR and HRV have an inverse relationship: during stress the pulse is higher and HRV is narrower, but during rest the pulse is lower and HRV is broader, when controlling for physical activity. Previous research has shown that HR and SCR tend to increase (i.e., SNS activation) with activating emotions and decrease with deactivating emotions (e.g., Benedek & Karnbak, 2010; Kreibig, 2010), despite the valence of emotions. Higher HRV (i.e., PNS activation), in turn, has been shown to be related to lower situational demands and relaxation, but also to more intense efforts in emotion regulation (Beauchaine & Cicchetti, 2019).

Previous research on achievement emotions focusing on individual (between-person) differences have been criticized for using trait-like assessments of achievement emotions that may be confounded with recall bias (see Goetz et al., 2013; Ketonen et al., 2018). In addition, they are unable to capture the effects of situational factors and temporal fluctuations of emotional reactions. Therefore, we aim to add to previous knowledge by estimating achievement emotions in achievement situations not only with questionnaires presented to participants but also using psychophysiological measures, namely heart rate variability and skin conductance. Recently, a growing number of studies measure achievement emotions with real-time assessments, in experience sampling or ecological momentary assessment designs (e.g., Ahmed et al., 2010; Bieg et al., 2013; Moeller et al., 2020; Tanaka & Murayama, 2014).

3. Control and value as antecedents of achievement emotions and related psychophysiological states

The schematic figure of our study based on control-value and flow-theories is shown in Fig. 1. The control-value theory of achievement emotions (Pekrun, 2000, 2006, 2017) suggests that the key predictors of achievement emotions are (a) subjective valuing of a particular task / activity or the importance of the outcome, and (b) appraisals of controllability in this activity or to be personally able to influence activities and their outcomes. In previous studies, the perception of control (e.g., competence belief, self-efficacy, capacity belief, agency beliefs) has consistently been found to be positively related with positive emotions and negatively related with negative emotions in between-person studies (Boekaerts, 2001; Clem et al., 2021; Dettmers et al., 2011; Frenzel et al., 2007; Goetz et al., 2008; Shao et al., 2020) as well as in studies investigating intrapersonal situational dynamics (Ahmed et al., 2010; Goetz et al., 2010; Tolvanen et al., 2011).

In our study we conceptualize *mastery experience* (or competence evaluation) to be a situation-specific equivalent of agency beliefs (see also Wigfield & Eccles, 2000; Malmberg et al., 2013) or an experience of success being a key source of self-efficacy (Bandura, 1997). In addition, we also measure situational task properties, that is, the *perceived challenge* in terms of subjective judgment of task difficulty and error rate describing the objective demandingness of the task (see also Pintrich, 2000; Malmberg et al., 2013). Perceptions of challenge are similar to perceptions of success expectancy or mastery, although the emphasis is on the task properties rather than on one's own capabilities (Pintrich, 2000; Tanaka & Murayama, 2014). In previous research, perceived task challenge has been found to be weakly negatively correlated with mastery experience (Malmberg et al., 2013; Schmitz & Skinner, 1993) and interest (Tanaka & Murayama, 2014) and positively related with unpleasant homework emotions (Dettmers et al., 2011). In addition, it has been shown that intrapersonal variation in mastery experiences and task challenge evaluations is larger than interpersonal variation (Schmitz & Skinner, 1993).

In previous research, the role of *value* (e.g., the subjective importance or personal relevance of success; see also Eccles et al., 1983; Wigfield & Cambria, 2010) in emotions seems to be more ambiguous than that of control. The control-value theory of achievement emotions (Pekrun, 2000, 2006, 2017) suggests that high perceived achievement value is associated with higher positive emotions and that negative emotions are expected be intensified if an individual attributes high value to avoiding failure (Pekrun, 2000, 2006). The expected relation of high value with higher levels of positive emotions has been consistently confirmed in previous research (Ahmed et al., 2010; Bieg et al., 2013; Frentzel et al., 2007; Goetz et al., 2010; Pekrun, 2000; Shao et al., 2020; Tanaka & Murayama, 2014). However, the predictive effect of subjective value on negative emotions has been shown to be either positive (e.g., Pekrun, 2000; Shao et al., 2020), negative (e.g., Ahmed et al., 2010; Boekaerts,

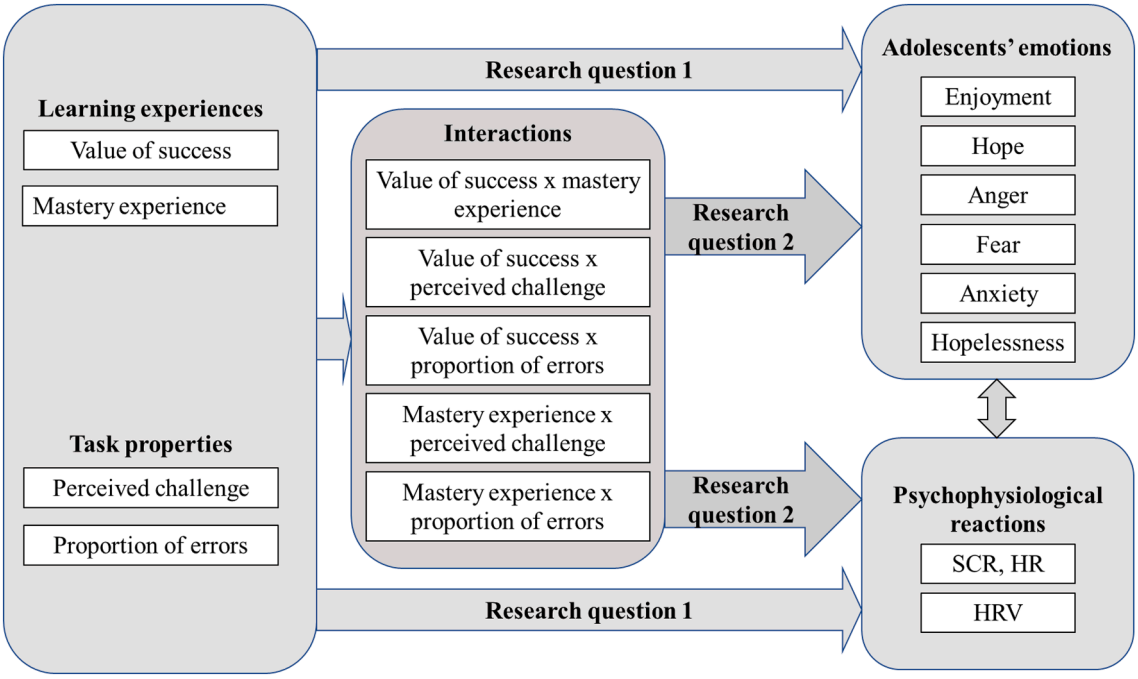


Fig. 1. Schematic figure of the study.

2001), or non-significant at between-person level (e.g., Ketonen et al., 2019). One explanation for this inconsistency between studies may relate to multiple ways of assessing value and whether value for success and value for avoiding failure have been differentiated (see also Shao et al., 2020).

Little seems to be known about the role of learning experiences and task properties in adolescents' psychophysiological states during emotion-evoking achievement situations. Physiological measures during emotion-evoking situations can provide valuable information about activation/deactivation of autonomic nervous system, which regulates a wide range of bodily functions (Kreibig & Gendolla, 2014). As an exception, Beh (1990) and Lackner et al. (2015) showed in their experiments that HR increased and HRV decreased during task completion among university students who had high efficacy beliefs and who attributed high importance of success, whereas for unmotivated and task-avoidant individuals HR and HRV did not change during task completion. In another type of study among adults, Venables and Fairclough (2009) showed that SCR was higher when individuals were given cumulative failure feedback regarding their performance.

4. Interplay of Value, level of challenge and mastery experience when predicting emotions and psychophysiological states

In addition to investigating the main effects of value, control and challenge, it is pivotal to shed light also on their interactions with experienced emotions and psychophysiological states (see also our schematic Fig. 1). The control-value theory of achievement emotions (Pekrun, 2000, 2006, 2017) proposes that control and value should interact to produce a combined effect on the prediction of achievement emotions. For instance, enjoyment of studying is expected when an individual feels both competent to master the task and attributes high value to success. In turn, fear of failure and anxiety are expected to be aroused when an adolescent perceives a lack of control over performance (cf. failure is possible) combined with high value of avoiding failure. The possibility of interaction effects between value and control has, however, been overlooked in many prior empirical studies. As an exception, in their experience sampling study among university students, Goetz et al. (2020) showed that the association between control appraisals and enjoyment, pride, and contentment was stronger in situations where high value appraisals were reported. Putwain et al. (2018) also showed in their longitudinal between-person study among sixth-graders that high achievement value in the mathematics domain amplified the positive relations between perceived control and enjoyment. Furthermore, Bieg et al. (2013) showed in their situational study among eighth-grade adolescents that it resulted in more intense feelings of anxiety when low control was combined with high value. Finally, in their between-person study among Chinese university students in the context of foreign language learning, Shao et al. (2020) showed that high task-value amplified the positive association between academic control and students' enjoyment, hope and pride and the negative association between academic control and students' anger, anxiety, shame, hopelessness and boredom.

The theory of flow or optimal experience (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988; see also Schneider et al., 2016), in turn, suggests that it is important to consider both the level of challenge and capabilities to master the activity when trying to understand optimal and non-optimal learning moments. It has been suggested that the appropriate level of challenge arouses a person's motivation to improve his or her abilities beyond what has been previously mastered (Dweck, 2006; Schneider et al., 2016). The condition when both challenge and mastery are high are thought to promote flow, that is, a state when an individual is so deeply engaged in a task that time loses its meaning and basic human needs are deferred (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988; see also Delle Fave & Massimi, 2005). Experiencing enjoyment and feeling successful, happy, confident, and active are related to these optimal learning moments. In turn, reporting anxiety is anticipated when low mastery is combined with high challenges (i.e., an overload of demand in relation to internal resources; see also Moneta & Csikszentmihalyi, 1996; Shernoff et al., 2003).

Empirical evidence for the mastery–challenge interactions has also been found. For example, Tolvanen et al. (2011) showed that when both perceived mastery and challenge were high, university students reported a heightened level of positive emotions (cf. flow experience), whereas when the sense of mastery was low and sense of challenge high, individuals reported a heightened level of negative emotions (i.e.,

anxiety). In another study, Inkinen et al. (2014) showed that high challenge–high mastery situations were related to a very active and positive core affect (see also Russell, 2003; Russell & Barrett, 2003), whereas high challenge–low mastery situations were related to an active but negative core affect among university students. Schneider et al. (2016) further showed among a large sample of secondary school students that when adolescents were challenged in their classes and were appropriately skilled they were more likely to report feeling confident, successful, and happy.

5. The present study

To overcome limitations of previous studies described above, we adopted the following approaches. First, our study included also measures of task properties (i.e., the level of task challenge) that have rarely been included in previous studies on the role of value and control in emotions. Second, as far as we know our study is the first study analyzing both intraindividual and interindividual variation and testing the interactions anticipated by both the control-value theory of achievement emotions (Pekrun, 2000, 2006, 2017) and the theory of flow or optimal experience (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988). Third, our study importantly contributes to previous literature as it examines not only adolescents' subjective emotions in achievement situations, but also related physiological states.

More specifically, the aim of this study was to address the following research questions (see theoretical figure, Fig. 1). The hypotheses when examining antecedents of emotions are based on the control-value theory of achievement emotions (Pekrun, 2000, 2006, 2017) and flow theory (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988; see also Schneider et al., 2016). Due to the relative lack of previous research in this area, no specific hypotheses were set regarding the antecedents of psychophysiological states.

(1) To what extent are learning experiences (value of success, mastery experience) and task properties (challenge) related to adolescents' emotions and psychophysiological states during achievement situations? H1a: High mastery experience is expected to promote higher levels of enjoyment and hope and lower levels of anger, fear, anxiety, and hopelessness. H1b: High value of success is expected to promote higher levels of enjoyment and hope, whereas no hypotheses are set regarding negative emotions. H1c: Regarding the task properties, high error rate and high perceived challenge are expected to promote higher levels of anger, fear, anxiety and hopelessness and lower levels of enjoyment and hope.
(2) Do learning experiences and task properties have an interactive role in adolescents' emotions and psychophysiological states during achievement tasks? More specifically:
    a) Does level of challenge moderate the associations of mastery experience with adolescents' emotions and psychophysiological states? H2a: It is expected that high task challenge strengthens the association between mastery experience and adolescent emotions so that high task challenge combined with high mastery experience contributes to heightened levels of positive emotions, whereas high task challenge combined with low mastery experience is expected to contribute to heightened levels of negative emotions and decreased positive emotions.
    b) Does level of challenge moderate the associations of value of success with adolescents' emotions and psychophysiological states? Due to the relative lack of previous research on this topic, no specific hypotheses regarding interaction effects were set.
    c) Does value of success moderate the associations of mastery experience with adolescents' emotions and psychophysiological states? H2c: It is expected that high value of success strengthens the association between mastery experience and emotions as such high value of success combined with high mastery experience will contribute to heightened levels of positive emotions. In contrast, no hypotheses are set regarding the moderation of negative emotions.

As girls tend to be physiologically more reactive and more vulnerable to experiencing negative emotions than boys (e.g., Fujita, Diener, & Sandvi, 1991; McManis, Bradley, Berg, Cuthbert, & Lang, 2001), and learning difficulties are related with heightened levels of negative achievement emotions (Rosenstreich et al., 2015; Sainio et al., 2019), these variables were introduced as control variables. In addition, as the tasks used in the present study included both math and reading tasks, the task subject (i.e., math vs reading) was controlled for as math tasks might evoke more intensive emotional reactions than those of reading (Sainio et al., 2019).

6. Material and methods

6.1. Participants

The participants of this study consisted of 190 (47 % girls) sixth-grade Finnish adolescents (mean age = 12.31 years; *SD* of age = 0.38 years) who participated in an experiment of simulated achievement situations during which they completed relatively more and relatively less challenging math and reading tasks in Grade 6 (spring). The adolescents came from 27 primary schools and from 52 classrooms. The procedures were in accordance with the principles of the Helsinki Declaration on research with human subjects. Written consent to participate was collected from participants and the research plan of the project was approved by the Human Sciences Ethics Committee of the local university.

Finnish was native language for all the adolescents. A total of 72 % of adolescents were from nuclear families, while 7 % were from single-parent families, 19 % were from blended families, and 2 % were from other types of families. A total of 4 % of the adolescents' parents were not educated beyond compulsory education, while 38 % had completed upper secondary education, 39 % held a bachelor's degree or vocational college degree, and 19 % held a master's degree or higher. Regarding the family structure and socioeconomic background, the sample was rather representative of the same age Finnish population (Official Statistics of Finland, 2016a; 2016b). However, because of the sampling procedure (see the next section), students with learning difficulties were over-represented and non-Finnish-speaking students underrepresented.

Finland is a modern industrialized nation with generation of youth growing up with access to the same types of media, culture and learning opportunities as youth in other Western and Nordic countries. The study includes mainstream students in the national educational system. Given our focus on biophysiological correlates of school achievement, we regard our sample of youth as a sample of 11–13 year old humans in an industrialized society.

6.2. Sampling procedure

Fig. 2 shows the sampling procedure and design of this study. All 190 participants completed four achievement tasks (each with a four minute time limit) that were either more or less challenging for their own skill level: two tasks of math (i.e., more challenging and less challenging) and two tasks of reading (i.e., more challenging and less challenging). The order of the tasks was randomized to minimize the effect of the task order (see Fig. 1). As our study was part of a broader study on learning difficulties, two-thirds of the adolescents selected for the experiment had difficulties primarily in math or primarily in reading. One-third of adolescents had no difficulties but were matched with the others according to fluid intelligence and gender distribution. Learning difficulties (i.e.,

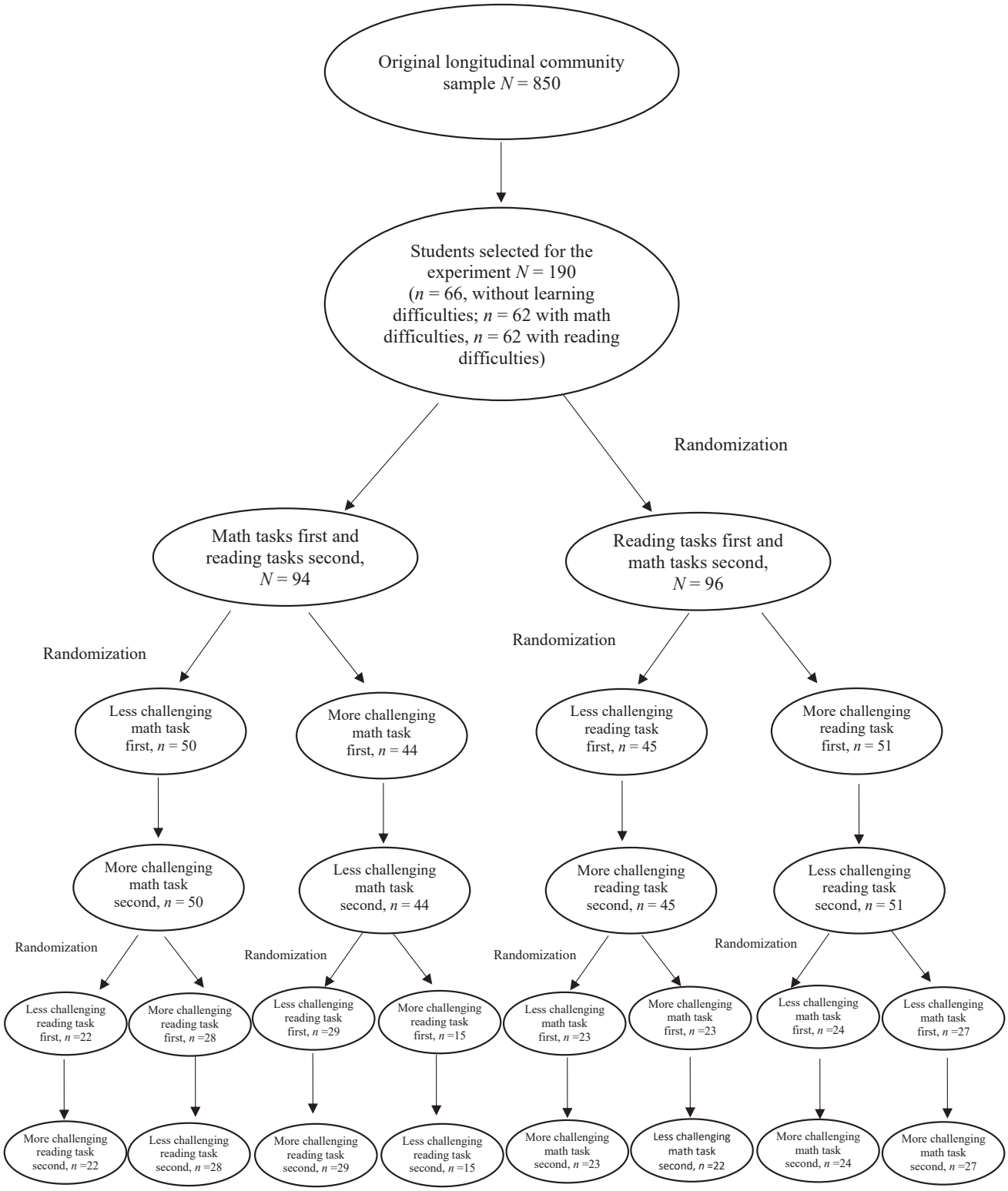


Fig. 2. The sampling procedure and design.

dummy-coded math difficulties, reading difficulties, and overlapping math and reading difficulties) were included as control variables in the statistical analyses.

The experiment occurred during normal school hours in an ambulatory laboratory built in a campervan parked in the schoolyard. Each experiment session was run by trained principal and assistant testers. During test sessions, adolescents' SCR and finger pulse volume (FPV) were recorded using a BrainVision QuickAmp amplifier and BrainVision Recorder 2.0 software. Adolescents' HR was registered using the BodyGuard (FirstBeat Technologies) system. The Bodyguard and BrainAmp systems' data were synchronized using an algorithm to precisely calculate the same time points, using HR and FPV, both of which measured heartbeat (Lampinen et al., 2018). During the test sessions the adolescents also filled in computerized questionnaires. Altogether the

test sessions took approximately 90 min, of which the simulated achievement tasks with questionnaires and math and reading tasks with varying challenge levels took about 30 min.

6.3. Description of achievement tasks

To guarantee equal cognitive demand for each participant within both relatively more and less challenging tasks, items within the tasks were selected according to participants' individual skill level, as determined by their scores in math and reading tests administered in Grade 6 fall (see Fig. 3). In both two math tasks (i.e., a relatively more and a relatively less challenging task, Fig. 3), a total of 20 calculation items with varying challenge levels were shown within a four-minute time frame (time remaining was shown on the screen). These were adapted from the arithmetic fluency test (Kanerva et al., 2019; Räsänen et al., 2009). The reading tasks were adapted from the nationally normed Reading Comprehension task (Lindeman, 1998). In both two reading tasks (i.e., a relatively more and a relatively less challenging task; Fig. 3), adolescents read silently a short text and answered multiple-choice questions probing the underlying meaning of the texts within a four-minute time limit (time remaining was shown on the screen). Adolescents were advised to do their best, and to try to be as quick as possible. No external feedback regarding their performance was given. In order to eliminate carry-over effects between the four tasks and to draw students' attention away from the experimental situation, the adolescents were asked to rate their appreciation for jokes/comics strips between every-two consecutive experimental tasks.

6.4. Measures

6.4.1. Dependent variables

Emotions. Students' achievement emotions were assessed with the Emotions in Achievement Situations (EAS) scale (Kiuru et al., 2014; see also Lehikoinen et al., 2019). The items included in the scale were adapted from the Achievement Emotions Questionnaire (AEQ; Pekrun et al., 2011) of the pool of items intended to measure test emotions during taking tests and exams and from the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) with the aim to assess emotions during real-time achievement situations. Adolescents' experienced emotions were assessed immediately after they had completed each task by asking "How did you feel during the task?" The applied items from the Emotions in the Achievement Situations (EAS) scale with a Likert scale ranging from 1 (disagree) to 5 (agree) were the following: (1) I was enthusiastic (enjoyment); (2) I was optimistic that I could do the task (hope); (3) I was angry/irritated (anger), (4) I was nervous/restless (anxiety); (5) I feared failing (fear), and (6) I felt hopeless (hopelessness). The items' test–retest reliabilities across the experimental tasks and separately for mathematics and reading domains were good ($\geq$0.70).

SCR. Adolescents' skin conductance was recorded utilizing two disposable electrodes (Ag/AgCI, AmbuNeurolone 710) on the palm of non-dominant hand, below the first and fourth digits. The electrodes were attached to a QuickAmp skin conductance (SC) module (Brain Products GmbH), which determines skin conductance with a DC instrumentation amplifier using 0.5 V constant voltage. The signal was amplified in DC mode and low-pass filtered at 250 Hz. The relaxed

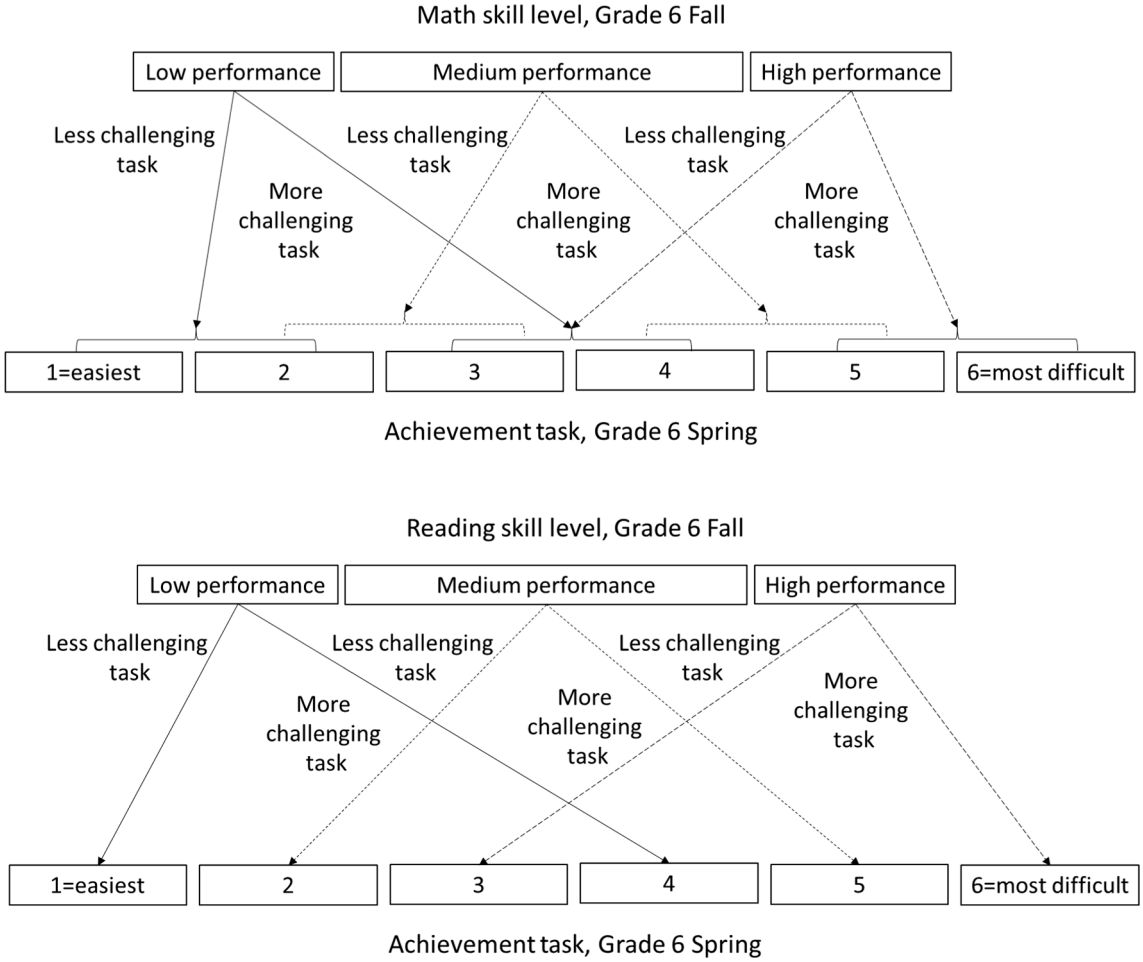


Fig. 3. Description of individual adaptation of challenge levels of achievement tasks.

chatting about daily activities prior to the actual test situation was the baseline, lasting approximately 5 min (see also Lehikoinen et al., 2019). Skin conductance data were divided into phasic and tonic SC components using the LEDALAB (V.3.4.6) toolbox for MATLAB (Benedek & Kaernbach, 2010). SC values were down sampled to 1 Hz, corresponding to the sampling rate of calculated HR variables (see also Lampinen et al., 2018). Because of the tasks' short duration, the analyses targeted phasic (reactive, rapidly changing peaks) skin conductance responses (SCR) rather than the smooth, slowly changing phasic baseline level. First, the SCR values were normalized according to the mean and standard deviation of each adolescent's baseline. Subsequently, the sum of peaks (above + 2 standard deviations) in the normalized SCRs were calculated and divided by the length of the task period separately for each task.

HR and HRV. Heartbeat data were measured utilizing a Firstbeat Bodyguard recording device (Firstbeat Technologies, Jyväskylä, Finland; https://www.firstbeat.com) recording continuously at a 1,000-Hz sampling rate. The device's two recording electrodes were placed under the collarbone on the body's right side and the ribcage on the left. Heartbeat data were automatically artefact corrected with the web-based Lifestyle assessment software utilizing a proprietary algorithm (Firstbeat Technologies 2014). Several heartbeat variables were calculated and stored at 1 Hz resolution. HR and HRV were the variables used in this study. HRV was determined by calculating the root mean square of successive heartbeat differences using a five-minute window centered on each time point (see also Goedhart et al., 2007; Penttilä et al., 2001). All raw values for HR and HRV were normalized like SCRs according to the mean and standard deviation of each student's baseline. Each adolescent's means were calculated across normalized HR and HRV separately for each task.

6.4.2. Independent variables

Value of success. The perceived value of success was measured before math and reading tasks with two questions (i.e., How important it is for you to succeed in math/reading? How important it is for you to do well in math/reading tasks? See also Eccles et al., 1983). Answers were given according to a Likert scale ranging from 1 (not important at all) to 5 (very important). Mean scores across the items were calculated for adolescents' value of success prior to math or reading task ($\alpha s \geq 0.70$).

Mastery experience. Adolescents reported their mastery experience after each task by responding two questions (i.e., How well do you think you succeeded in the task? How well do you think you succeeded in the task when compared to same-aged peers?) on a Likert scale ranging from 1 (very poorly) to 5 (very well; see also Eccles & Wigfield, 1995; Spinath & Steinmayr, 2008). The mean scores across the items were calculated to measure mastery experience in each math or reading task ($\alpha s \geq 0.70$).

Level of task challenge. Adolescents reported their perceptions of task challenge after each task by responding two questions (i.e., How difficult was the task? How difficult was the task compared to what you expected? See also Malmberg et al., 2013) on a Likert scale ranging from 1 (very easy/much easier) to 5 (very difficult/much more difficult). The mean scores for the questions were calculated to measure experienced task challenge ($\omega s \geq 0.70$). As another measure of task challenge, error rate (%) was calculated in each task by dividing the number of incorrect answers in the task by the number of completed task items.

6.4.3. Control variables

The controlled covariates in the statistical analyses consisted of students' gender (1 = girl, 2 = boy), task subject (0 = reading, 1 = math), reading difficulty (0 = others, 1 = reading difficulty), math difficulty (0 = others, 1 = math difficulties), and reading + math difficulties (0 = others, 1 = reading difficulties + math difficulties). Tasks and cut-offs used for identifying adolescents with reading difficulty and/or math difficulties are described in detail in (Sainio et al., 2019). Identification of math difficulties (MD) was based on the time-limited (3 min) Arithmetic Fluency Test (see also Räsänen et al., 2009) containing 28 items of addition, subtraction, multiplication, and division (α = 0.82). The identification of reading difficulty (RD) was based on the arithmetic mean of standardized scores in three tests of reading fluency (α = 0.87). First, in the Word Identification test, students were instructed to identify as many words as possible within the time limit (1 min and 30 s) in word chains (25), each comprising four different words written without spaces (e.g., "tailorbilberryreadyhorse" -> "tailor|bilberry|ready|horse"). Second, in the Spelling Errors test, students were instructed to mark as many spelling errors (incorrect, extra, or missing letter) as possible in 100 words within the time limit (3 min and 30 s) (e.g., carot -> car|ot). Third, in the short version (36 items) of the Salzburg reading-fluency test (see also Landerl, Wimmer & Moser, 1997), students were instructed to mark the truthfulness (true / false) of as many sentences read silently as possible within the time limit (1 min and 30 s) (e.g., "To pass a driving test, it is necessary to have good skills in swimming.").

6.5. Statistical analyses

After first exploring descriptive statistics, the statistical analyses were conducted using a multilevel modeling technique (Heck & Thomas, 2015; Muthen & Muthen, 1998–2021), where four repeated measurements (i.e., relatively more and less challenging tasks in both math and reading; level 1; within-person level) were nested within individuals (level 2; between-person level). Together with the two-level analyses, the Type = Complex approach (Muthen & Muthen, 1998–2021) was applied to account for the classroom level. This method adjusts the standard errors for the clustering (classrooms), safeguarding against Type 1 errors. Multilevel modelling allowed us to investigate the associations of value of success, level of challenge and mastery experience with self-reported emotions and psychophysiological states simultaneously at the within-person (task) and between-person (adolescents) levels when accounting for classroom differences, as well as to include within- and between-level predictors in the models.

The models were conducted along the following steps. First, intraclass correlations and within- and between variance estimates were calculated for the independent and dependent variables between tasks and persons. Second, within-person and between-person level correlations were investigated. Task subject (i.e., math vs reading) was specified as a within-level variable, whereas gender and learning difficulties were treated as between-level variables. All the other variables were modelled at both levels.

Finally, separate multilevel models to predict each of the self-reported emotions (i.e., enjoyment, hope, anger, anxiety, fear, hopelessness) and ANS variables (i.e., SCR, HR, HRV) were specified. At both levels, self-reported emotions and ANS variables were predicted by value of success, perceived challenge, extent of errors, and mastery experience in the task, while controlling for the effect of task subject at within level and the effects of gender and learning difficulties at between level. In addition, the interaction terms between value of success, perceived challenge, extent of errors, and mastery experience (i.e., Value × Mastery Experience, Perceived Challenge × Mastery Experience, Errors × Mastery experience, Value × Perceived Challenge, and Value × Errors) were estimated at both levels. At the between-level, the interaction terms were calculated between the group-mean (i.e., individual) aggregated variables to enable estimation of interaction terms at both levels. Only statistically significant interaction terms were included

in the final models. Three-level interactions were also tested but as none of them was significant they were omitted from the final models that included only the hypothesized interaction terms.

The analyses were performed with the Mplus statistical package (Version 8.4, Muthén & Muthén, 1998–2021). There was no missing data (0 %) in the adolescent-rated emotions. In turn, information on SCR was missing for 19 % and on HR and HRV for 25 % of adolescents. For the moderator variables, the proportion of missingness was 0 %. Full-information maximum likelihood estimation was used, which allowed us to use all the information in the data with non-normality robust standard errors (Muthén & Muthén, 1998–2021).

7. Results

7.1. Descriptive statistics

Table 1 shows the descriptive statistics. Adolescents' error rate was higher in the relatively more than less challenging tasks with moderate to large effect sizes (*d* for math tasks = 1.05; d for reading tasks = 0.52), suggesting that the manipulating the level task challenge was successful.

7.2. Intraclass correlations and Within-and Between-Level correlations

Intraclass correlations (ICC) were calculated to determine what proportion of the variance in observed variables was attributed to differences between individuals and what proportion to differences between task conditions within individuals (i.e., situational level). ICCs and within- and between-variance estimates of observed variables are shown in Table 2. The results revealed that between-person differences were largest for value of success (68 %) and mastery experience (38 %), whereas most of the variance in level of challenge (92 %) and extent of errors (81 %) was attributed to the situational level. Regarding experienced emotions and ANS variables, 45 % to 70 % of the total variance was explained by differences between individuals, whereas the rest of the variation was explained by the situational level.

Table 3 presents within- and between-level correlations between the observed variables. Within-person correlations are shown below the diagonal and between-person correlations are shown above the diagonal.

7.3. Multilevel models

The results of the multilevel models for adolescents' emotions are shown in Table 4 and for adolescents' psychophysiological states in Table 5.

Main effects. The within-person level results for experienced emotions (Table 4) showed, first, that high *value of success* was related to higher levels of enjoyment and hope during the task. Second, high *mastery experience* was related to higher levels of enjoyment and hope and lower levels of anger, anxiety, and hopelessness. Third, high *perceived task challenge* was associated with lower levels of enjoyment and hope and higher levels of anxiety and hopelessness, whereas *high error rate in the task* was related to lower levels of enjoyment and hope and higher levels of anxiety, fear, and hopelessness. The within-person level results for psychophysiological states (Table 5) showed that high error rate was related to higher HRV.

The results at the between-person level for experienced emotions (Table 4) showed that high value of success was related to higher hope, and high mastery experience was related to higher enjoyment and hope and lower fear. High perceived task challenge, in turn, was related to lower enjoyment, and high error rate was related to higher hopelessness. Regarding the psychophysiological variables (Table 5) none of the main effects of value, challenge, and mastery experience were significant.

Interactive effects. Six of the tested interaction terms at the within-

Table 2
Intraclass correlations and between-person (individual-level) and within-person (situational level) level variance estimates of observed variables ($n_{between}$ = 146–190, n_{within} = 583–760), when controlling for classroom differences *Note.* *** p <.001, * p <.05.

		Between-level		Within-level	
Predictors	ICC	Variance	S.E	Variance	S.E
Value of success	0.68***	0.36***	0.04	0.17***	0.03
Mastery experience	0.38***	0.18***	0.03	0.30***	0.03
Perceived challenge	0.08*	0.06*	0.03	0.72***	0.06
Extent of errors (%)	0.19***	0.01***	0.001	0.04***	0.002
Dependent variables					
Enjoyment	0.45***	0.51***	0.06	0.63***	0.05
Hope	0.46***	0.42***	0.06	0.50***	0.04
Anger	0.55***	1.22***	0.04	0.17***	0.04
Anxiety	0.50***	0.31***	0.07	0.31***	0.05
Fear	0.55***	0.72***	0.07	0.58***	0.05
Hopelessness	0.61***	0.46***	0.09	0.29***	0.04
SCR	0.67***	28.64*	11.28	14.05***	3.93
HR	0.70***	2.33***	0.45	0.98***	0.11
HRV	0.54***	1.84***	0.51	1.56***	0.27

Table 1
Means and standard deviation of observed variables during achievement tasks (n = 146–190).

	Math task				Reading task			
	More challenging		Less Challenging		More challenging		Less challenging	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Self-reported emotions								
Enjoyment	3.00	1.07	3.42	1.11	3.85	0.93	3.80	0.92
Hope	3.04	1.00	3.42	0.90	3.73	0.89	3.66	0.90
Anger	1.35	0.80	1.24	0.62	1.14	0.45	1.14	0.50
Anxiety	1.70	1.02	1.46	0.77	1.25	0.61	1.27	0.61
Fear	2.42	1.20	2.25	1.12	2.04	1.09	2.01	1.11
Hopelessness	1.72	1.02	1.47	0.82	1.34	0.73	1.36	0.81
ANS variables								
SCR	4.00	6.61	3.56	6.01	3.77	6.10	3.74	7.40
HR	−0.30	1.82	−0.33	1.75	−1.24	1.83	−1.21	1.66
HRV	0.33	1.71	0.22	1.48	0.91	2.02	0.77	2.04
Level of challenge								
Extent of errors (%)	0.39	0.24	0.18	0.15	0.35	0.22	0.24	0.20
Perceived challenge	3.58	0.74	3.09	0.77	2.55	0.78	2.51	0.78

Table 3
Estimated correlations of observed variables (between-person level above the diagonal and within-person level below the diagonal), ($n_{between}$ = 146–190, n_{within} = 583–760).

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
1. Value of success	–	$.36^{a}$	-0.11	0.05	0.01	$.32^{b}$	-0.12	-0.08	0.11	0.01	-0.00	0.18	-0.10	$-.23^{b}$	-0.03	0.02	$-.22^{b}$	–
2. Mastery experience	$.21^{a}$	–	$-.44^{a}$	$-.18^{b}$	-0.01	$.43^{a}$	-0.16	-0.09	$-.25^{b}$	-0.08	-0.10	0.09	-0.16	0.09	0.06	-0.04	$-.15^{b}$	–
3. Perceived challenge	-0.00	$-.56^{a}$	–	$.21^{b}$	$.25^{b}$	-0.06	$.24^{c}$	0.05	0.11	0.13	0.04	-0.09	0.15	0.07	0.06	-0.05	0.05	–
4. Errors (%)	0.02	$-.19^{a}$	$.22^{a}$	–	0.10	-0.03	0.08	-0.07	$.18^{c}$	$.21^{c}$	0.19	0.08	0.06	$-.16^{c}$	-0.10	-0.05	$.30^{b}$	–
5. Enjoyment	$.40^{a}$	$.64^{a}$	$-.57^{a}$	$-.20^{a}$	–	$.48^{a}$	$-.18^{c}$	-0.16	-0.02	-0.11	-.24c	$-.18^{c}$	-0.03	0.03	0.08	-0.12	0.08	–
6. Hope	$.25^{b}$	$.63^{a}$	$-.51^{a}$	$-.18^{a}$	$.63^{a}$	–	-0.17	-0.11	-0.16	-0.12	-0.19	-0.03	$-.24^{b}$	$.22^{b}$	0.14	-0.15	0.08	–
7. Anger	0.01	$-.33^{a}$	$.18^{b}$	0.09	$-.29^{b}$	$-.22^{b}$	–	$.79^{a}$	$.31^{a}$	$.63^{a}$	-0.02	-0.08	0.11	0.13	-0.02	-0.00	-0.12	–
8. Anxiety	-0.04	$-.40^{a}$	$.38^{a}$	$.21^{a}$	$-.36^{a}$	$-.32^{a}$	$.38^{a}$	–	$.37^{a}$	$.58^{a}$	-0.05	-0.07	0.04	0.03	-0.10	0.09	-0.10	–
9. Fear	0.01	$-.24^{b}$	$.27^{a}$	$.17^{a}$	$-.22^{b}$	$-.22^{b}$	$.17^{b}$	$.24^{a}$	–	.44a	0.04	0.18	0.08	$-.21^{b}$	-0.15	0.15	0.09	–
10. Hopelessness	-0.04	$-.53^{a}$	$.36^{a}$	$.21^{a}$	$-.38^{a}$	$-.39^{a}$	$.45^{a}$	$.47^{a}$	$.33^{a}$	–	-0.06	-0.08	0.13	-0.01	-0.04	0.03	0.02	–
11. SCR	-0.02	0.01	0.02	0.01	0.06	0.03	-0.04	0.03	0.02	0.02	–	.20b	-0.01	-0.10	-0.10	-0.09	$.19^{d}$	
12. HR	0.02	$-.23^{b}$	$.23^{a}$	0.00	$-.24^{b}$	$-.19^{b}$	$.09^{b}$	$.15^{a}$	$.13^{c}$	$.15^{b}$	.16c	–	$-.37^{a}$	-0.16	0.08	0.02	0.02	–
13. HRV	0.07	0.09	$-.11^{c}$	$.12^{c}$	$.15^{c}$	0.10	-0.01	-0.05	-0.08	-0.03	-0.06	$-.42^{a}$	–	-0.15	0.02	-0.10	-0.03	–
14. Gender[1]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	$.14^{c}$	$-.15^{c}$	0.04	–
15. RD	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	$-.29^{a}$	$-.27^{a}$	–
16. MD	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	$-.28^{a}$	–
17. RD + MD	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
18. Task subject[2]	$.15^{a}$	$-.35^{a}$	$.49^{a}$	-0.01	$-.35^{a}$	$-.31^{a}$	$.19^{a}$	$.28^{a}$	$.20^{a}$	$.21^{a}$	-0.01	$.48^{a}$	$.23^{a}$	–	–	–	–	–

Note. $^{a}p < .001$, $^{b}p < .01$, $^{c}p < .05$. [1]0 = girl, 1 = boy, [2] 0 = reading task, 1 = math task. Task subject = within-person level variable; gender, RD, MD, RD + MD = between-person variables; other variables are analyzed at within- and between-person levels.

level and five of the tested interaction terms at the between-level were significant when predicting adolescents' experienced emotions and psychophysiological states (Tables 4 and 5). The results showed, first, that Mastery Experience × Perceived Challenge interaction term was significant when predicting enjoyment, anger, anxiety, hopelessness, and SCR at the within-person level (for interpretations, see Fig. 4): low mastery experience was related to lower enjoyment, higher anger, anxiety and hopelessness, and increased SCR especially during those tasks that adolescents perceived highly challenging, whereas no similar effects of mastery experience were found in tasks that adolescents perceived non-challenging. Furthermore, Mastery Experience × Perceived Challenge interaction term was also significant when predicting hope at the between-person individual level (see Fig. 4), so that when adolescents generally perceived high levels of challenge (independent of the task) their experience of high mastery was related to higher hope, whereas if adolescents perceived low levels of challenge (independent of the task) their experienced mastery was unrelated to hope.

Second, the results for interactions showed that the Value of Success × Errors interaction term was significant when predicting adolescent anger and anxiety at the between-person level (see Fig. 5). When adolescents' error rate was generally high (independent of the task), low value of success was related to higher levels of anger and anxiety, whereas if error rate was low, value of success was unrelated to anger and anxiety.

Finally, the results for interactions showed that the Mastery Experience x × Success Value interaction term was significant when predicting SCR and HRV at the within-person level (see Fig. 6) so that when adolescents perceived high value of success in a task, their high mastery experience in a task was related to increased SCR and decreased HRV during that task. By contrast, if adolescents perceived low value of success in a task, their mastery experience in a task was related to decreased SCR and increased HRV during the task.

8. Discussion

This study provided novel understanding about the roles of learning experiences (value, mastery) and task properties (challenge) in adolescents' emotions and psychophysiological states. Following our theoretical frame (Fig. 1) we proposed moderation-hypotheses (e.g., Pekrun, 2006; 2017; Csikszentmihalyi, 2008). The results of multilevel modelling showed that aside from the anticipated main effects at within- and between-person levels, significant interaction effects were also found. Perceived challenge moderated the association of mastery experience with students' experienced emotions and SCR, whereas error rate moderated the association of success value with anger and anxiety. Success value also moderated the association of mastery experience with SCR and HRV. In general, the relations between learning appraisals and emotions were more consistent at the within- than the between-person level and different emotions were also more clearly separate at this level. The results underscore the importance of individuals' situational appraisals and the extent of errors as eliciting factors with respect to emotions and psychophysiological states in achievement situations.

8.1. *Main effects of value, mastery, and challenge on emotions and psychophysiological states*

Our first aim was to examine intraindividual and interindividual main effects of value of learning experiences (success, mastery) and task properties (challenge) on adolescents' emotions during achievement tasks, when controlling for the effects of gender, task subject (i.e., math vs reading), learning difficulties, and classroom differences. The results showed, first, in line with H1a and our schematic figure (Pekrun, 2000, 2006, 2017; see also Ahmed et al., 2010; Boekaerts, 2001; Clem et al., 2021) that high mastery experience was related to higher enjoyment and hope and lower anger, fear, anxiety, and hopelessness. Mastery

Table 4
Multilevel models for experienced emotions.

	Dependent variable											
	Enjoyment		Hope		Anger		Anxiety		Fear		Hopelessness	
	Within-level		Within-level		Within-level		Within-level		Within-level		Within-level	
Independent variable	Stand β	s.e	Stand β	s.e	Stand β	s.e	Stand β	s.e	Stand β	s.e	Stand β	s.e
Task subject[1]	-0.14**	0.04	-0.07	0.04	0.08	0.06	0.11**	0.04	0.10*	0.05	-0.01	0.03
Value of success	0.33***	0.06	0.15*	0.07	0.08	0.14	-0.01	0.13	-0.01	0.11	0.08	0.10
Mastery experience	0.30***	0.05	0.42***	0.06	-0.24**	0.09	-0.19**	0.06	-0.10	0.09	-0.38***	0.08
Perceived challenge	-0.34***	0.06	-0.24***	0.06	0.02	0.08	0.21**	0.05	0.12	0.07	0.17**	0.06
Errors (%)	-0.08*	0.04	-0.06*	0.03	0.03	0.05	0.12*	0.05	0.12**	0.04	0.07+	0.04
Value × mastery experience												
Mastery experience × perceived challenge	0.08*	0.04			-0.18**	0.07	-0.16**	0.05			-0.23***	0.05
Mastery experience × errors												
Value × perceived challenge									0.12*	0.04		
Value × errors												
R^2 (within)	$R^2 = 0.58$		$R^2 = 0.45$		$R^2 = 0.13$		$R^2 = 0.23$		$R^2 = 0.11$		$R^2 = 0.32$	
	Between-level		Between-level		Between-level		Between-level		Between-level		Between-level	
Independent variable	Stand β	s.e	Stand β	s.e	Stand β	s.e	Stand β	s.e	Stand β	s.e	Stand β	s.e
Gender[2]	-0.01	0.07	0.25***	0.06	0.09	0.07	-0.01	0.08	-0.11	0.07	0.02	0.07
RD	0.05	0.08	0.12	0.09	-0.03	0.00	-0.12	0.09	-0.04	0.08	-0.01	0.07
MD	-0.07	0.09	-0.02	0.08	0.01	0.09	0.02	0.10	0.14	0.08	0.03	0.09
RD & MD	0.06	0.10	0.20	0.11	-0.08	0.08	-0.16	0.09	0.11	0.09	-0.02	0.10
Value of success	0.03	0.11	0.31**	0.13	-0.10	0.17	-0.08	0.18	0.23	0.16	-0.01	0.12
Mastery experience	0.17*	0.08	0.39***	0.12	-0.10	0.12	-0.10	0.12	-0.29**	0.10	-0.07	0.11
Perceived challenge	0.31***	0.09	0.11	0.08	0.15	0.13	0.01	0.11	0.01	0.10	0.05	0.09
Errors (%)	0.04	0.07	0.01	0.06	0.07	0.08	-0.06	0.10	0.07	0.09	0.20*	0.10
Value × mastery experience												
Mastery experience × perceived challenge			0.20*	0.08								
Mastery experience × errors												
Value × perceived challenge												
Value × errors					-0.19**	0.09	-0.16*	0.08				
R^2 (between)	$R^2 = 0.11$		$R^2 = 0.41$		$R^2 = 0.14$		$R^2 = 0.08$		$R^2 = 0.18$		$R^2 = 0.06$	

Note. Paths are presented as standardized estimates. *** $p < .001$, ** $p < .01$, * $p < .05$. [1]0 = reading task, 1 = math task [2]0 = girl, 1 = boy. Correlations between predictors were allowed. Only statistically significant interaction terms are included in the final models.

experience explained both between-person and situational/task-variation in positive emotions. In regards to negative emotions, lower mastery experience was mainly related to situationally experienced anger, anxiety, and hopelessness, and to a fear level typical of an individual across the situations. High mastery experience implies a sense of high control in achievement situations (Pekrun, 2017) that might efficiently promote positive emotions and increase openness to flexible problem-solving strategies (Fredrickson, 2001). In contrast, experience of low mastery when performing a task is likely to increase anger, anxiety, fear, and even hopelessness (Ahmed et al., 2010). Hence, our results suggest that providing adolescents with opportunities for success and related mastery experiences might effectively enhance their positive achievement emotions and decrease their negative achievement emotions (Seligman & Csikszentmihalyi, 2000).

Second, the results showed, in line with H1b and our schematic figure (Pekrun, 2006, 2017; see also Ahmed et al., 2010; Bieg et al., 2013; Frentzel et al., 2007; Shao et al., 2020; Tanaka & Murayma, 2014) that high value of success was related to higher levels of enjoyment and hope. Value of success was related to hope at both within-and between-person level, whereas the association between value of success and enjoyment was significant only at the within-person level. The results suggest that adolescents tend to be more hopeful and enjoy achievement tasks more when they attribute high value to successful task completion. In line with the control-value theory of achievement emotions (Pekrun, 2006, 2017), this suggests that efforts to promote the personal relevance and meaningfulness of learning and achievement activities could serve to enhance positive achievement emotions (see also Goetz et al., 2010). No significant main effects for the value of success on negative emotions were found at within-person or between-person levels. One explanation for the lack of results concerning negative emotions is that we measured only value of success and lacked a separate measure for value of avoiding failure. The control-value theory of achievement emotions (Pekrun, 2000, 2006, 2017) suggests that negative emotions should be intensified if an individual attributes high value for avoiding failure (Pekrun, 2000, 2006). It is possible that the phenomenon is different when negative emotions are examined in relation to the value of success.

Third, in line with H1c, the results regarding the level of task challenge showed (see also Dettmers et al., 2011; Tanaka & Murayama, 2014) that high perceived challenge (see also Malmberg et al., 2013; Pintrich, 2000) was related to both lower levels of positive emotions (enjoyment, hope) and higher levels of negative emotions (anger, fear, anxiety and hopelessness) especially at the within-person level. Furthermore, a high number of errors (perhaps related to a sense of struggling and failing in the task) triggered anger, fear, and anxiety especially at the within-person level and more hopelessness at both levels. The results underscore the importance of paying attention to the relationship between adolescents' skills and task demands when aiming to stimulate positive emotions and decreasing negative emotions during task completion (see Spinath & Steinmayr, 2008; Vygotski, 1978).

The within-person level results for psychophysiological states showed that a high proportion of errors in the task was related to higher HRV. Previous research has shown that increased HRV (i.e., PNS activation) is related to lower situational demands and relaxation, but also to more intense efforts in emotion regulation (Beauchaine & Cicchetti, 2019). The found results for HRV could be tentatively interpreted so that a high number of errors (perhaps experienced as failures) might stimulate adolescents' increased efforts in negative emotion regulation during task completion. Alternatively, these youth might have disengaged from the task, and not felt stressed about careless mistakes.

Table 5
Multilevel models for ANS variables.

	Dependent variable					
	SCR		HR		HRV	
	Within-level		Within-level		Within-level	
Independent variable	Stand β	s.e	Stand β	s.e	Stand β	s.e.
Task subject [1]	-0.01	0.03	0.47***	0.06	-0.23***	0.06
Value of success	-0.02	0.10	-0.04	0.12	0.11	0.13
Mastery experience	-0.07	0.08	-0.09	0.09	0.02	0.07
Perceived challenge	0.08	0.06	-0.05	0.06	-0.03	0.07
Errors (%)	0.01	0.04	0.01	0.05	0.12*	0.06
Value × mastery experience						
Mastery experience × perceived challenge	-0.12*	0.05				
Mastery experience × errors						
Value × perceived challenge						
Value × errors						
R^2 (within)	$R^2 = 0.01$		$R^2 = 0.23$		$R^2 = 0.08$	
	Between-level		Between-level		Between-level	
Independent variable	Stand β	s.e	Stand β	s.e	Stand β	s.e.
Gender [2]	-0.09	0.07	-0.10	0.10	-0.18*	0.09
RD	-0.07	0.07	0.15	0.08	-0.04	0.09
MD	-0.08	0.09	0.08	0.09	-0.18*	0.08
RD & MD	0.10	0.10	0.11	0.10	-0.16+	0.07
Value of success	-0.01	0.12	0.18	0.13	-0.22	0.14
Mastery experience	-0.06	0.11	0.02	0.09	-0.09	0.12
Perceived challenge	-0.01	0.09	-0.09	0.10	0.09	0.10
Errors (%)	0.12	0.10	0.05	0.09	0.07	0.09
Value × mastery experience	0.13*	0.04			-0.26*	0.13
Mastery experience × perceived challenge						
Mastery experience × errors						
Value × perceived challenge						
Value × errors						
R^2 (between)	$R^2 = 0.09$		$R^2 = 0.08$		$R^2 = 0.14$	

Note. Paths are presented as standardized estimates. *** $p < .001$, ** $p < .01$, * $p < .05$, + $p < .10$. [1]0 = reading task, 1 = math task [2]0 = girl, 1 = boy. Correlations between predictors were allowed. Only statistically significant interaction terms are included in the final models.

8.2. *Interactive effects of value, mastery and challenge on emotions and psychophysiological states*

Our second aim was to investigate whether learning experiences (value, mastery) and task properties (challenge) have an interactive role in adolescents' emotions and psychophysiological states. First, the results revealed that perceived challenge moderated the relationship between mastery experience and hope at the between-person level and between mastery experience and enjoyment, anger, anxiety, hopelessness, and SCR at the within-person level. The results for hope at the between-person (individual) level supported H2a and our schematic model (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988) by showing that high task challenge strengthened the association between mastery experience (independent of the task) and hope: high perceived task challenge combined with high mastery experience contributed to heightened levels of hope during the task. This suggests that adolescents experience enhanced hope and perhaps pride when they perceive higher than average levels of both challenge and mastery, indicating that a task is within one's mastery level and not overwhelmingly difficult (see also Moneta & Csikszentmihalyi, 1996; Scheiner et al., 2016; Shernoff et al., 2003;). At the same time, no similar interpretation of the mastery–challenge interaction was found for enjoyment. It is possible that adolescents nevertheless did not experience any strong flow moments during the experimentally built simulated achievement situations.

Furthermore, the results for anger, anxiety, hopelessness, and enjoyment at the within-person (situational) level supported H2a and our schematic model (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988) by showing that low mastery experience combined with high task challenge was related to heightened anger, anxiety and hopelessness and decreased enjoyment during achievement situations. In addition, high mastery experience in the task was related to increased SCR (i.e., SNS activation) when adolescents experienced high challenge in the task. The result for SCR also supports the flow theory (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988) by showing that when low mastery is combined with a high level of challenge, anticipated anxiety can be observed also in the physiological reaction. The results are also in line with those of Venables and Fairclough (2009), who observed increased SCR when adult participants received cumulative failure feedback in regard to their performance. Overall, it is possible that if an adolescent experiences too much anxiety or stress in achievement situations (at both the psychological and physiological level) they may become frozen or disengaged from the activity (see also Salmela-Aro & Upadyaya, 2014).

Second, the results revealed that error rate moderated the association of success value with anger and anxiety at the between-person level by showing that a high number of errors combined with a low value of success was related to heightened levels of anger and anxiety. Due to the relative lack of previous research on this topic, no specific hypotheses regarding interaction effects were originally set. One possible explanation for the results is that if adolescents value success highly, they also tolerate more errors without substantial frustration because succeeding despite the challenge is important for them. Another possible explanation is that adolescents with low value of success exert less effort and make more errors in the tasks because they do not care about the outcome (see also Putwain et al., 2018). They may also generally be frustrated by the achievement situation itself rather than reacting emotionally to specific task properties. Further research is needed to shed light on these alternative underlying mechanisms. Future studies should also measure value of success and value of failure as separate constructs (see also Pekrun, 2006; Shao et al., 2020) to shed further light on possible interactive effects with the task challenge on experienced

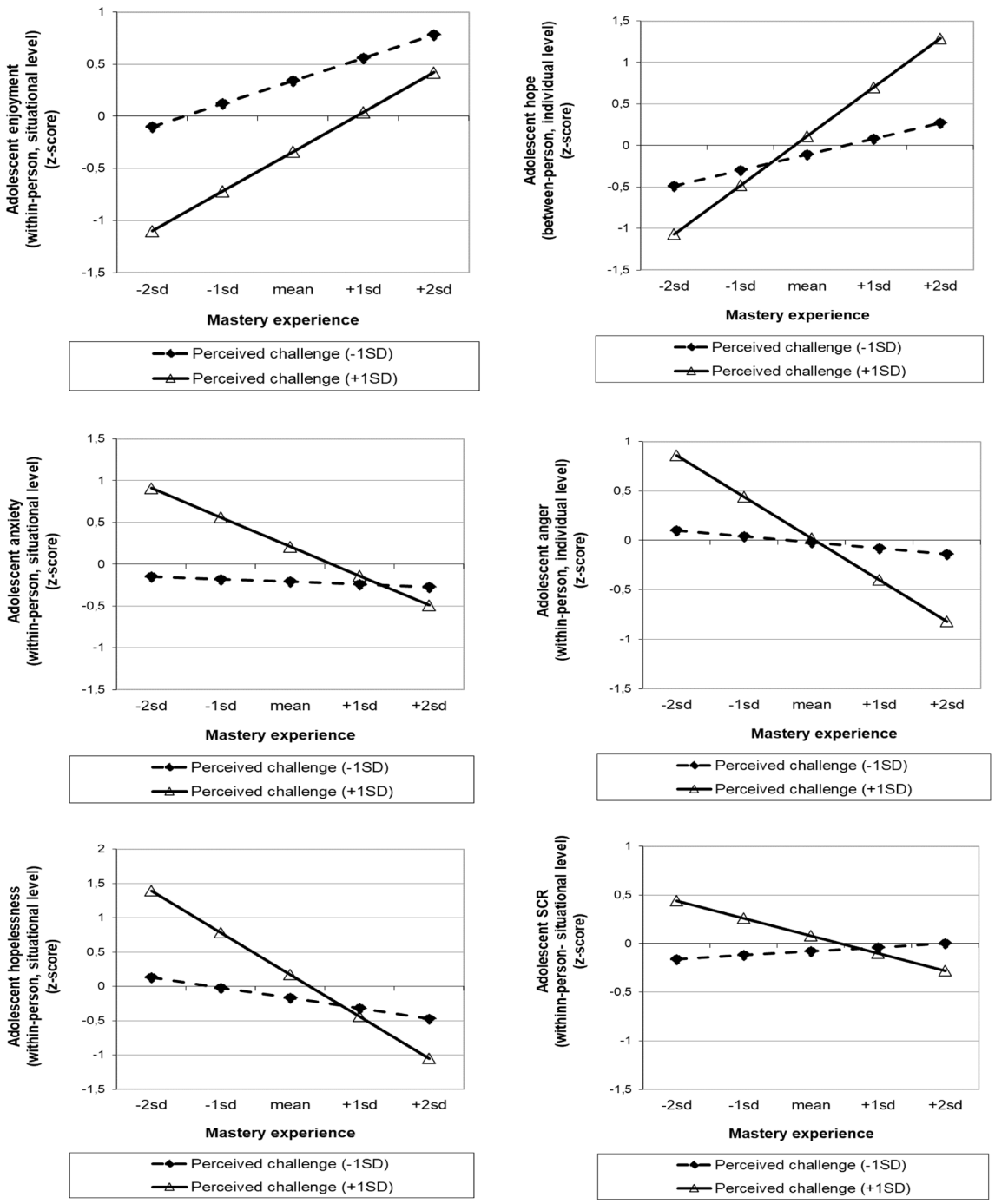


Fig. 4. Adolescent perceived challenge as a moderator of the associations between mastery experience and emotional and physiological states: between mastery experience and enjoyment (upper left), between mastery experience and hope (upper right), between mastery experience and anger (middle left), between mastery experience and anxiety (middle right), between mastery experience and hopelessness (bottom left), and between mastery experience and SCR (bottom right).

emotions.

Third, the results showed no moderation effect for success value in the relationship between mastery experience and adolescents' experienced emotions. These results are against H2c and our schematic model (Pekrun, 2006, 2017), in which we expected that high value of success combined with high mastery experience would contribute to heightened levels of positive emotions. Our results also differ from the results of some previous between-person studies (Putwain et al., 2018) and studies using an experimental sampling method among secondary or university students in real-time situations (e.g., Bieg et al., 2013; Goetz et al., 2010). One possible explanation for the lack of Value of Success × Mastery Experience interactions when predicting emotions relates to differences in study designs, sample, and control variables. Our study also included measures for the level of task challenge that have rarely been included in the studies which examine the role of value and control in emotions. Another possible explanation for the lack of expected interactions is that only four repeated measurements (i.e., tasks) were nested within adolescents. Although from medium to large intraclass correlations were found and despite the fact that a sample size of almost 200 adolescents is likely to partly compensate possible power challenges related to a small number of within-level units (see also Arend & Schäfer, 2019), it is still possible that some of our complicated multilevel

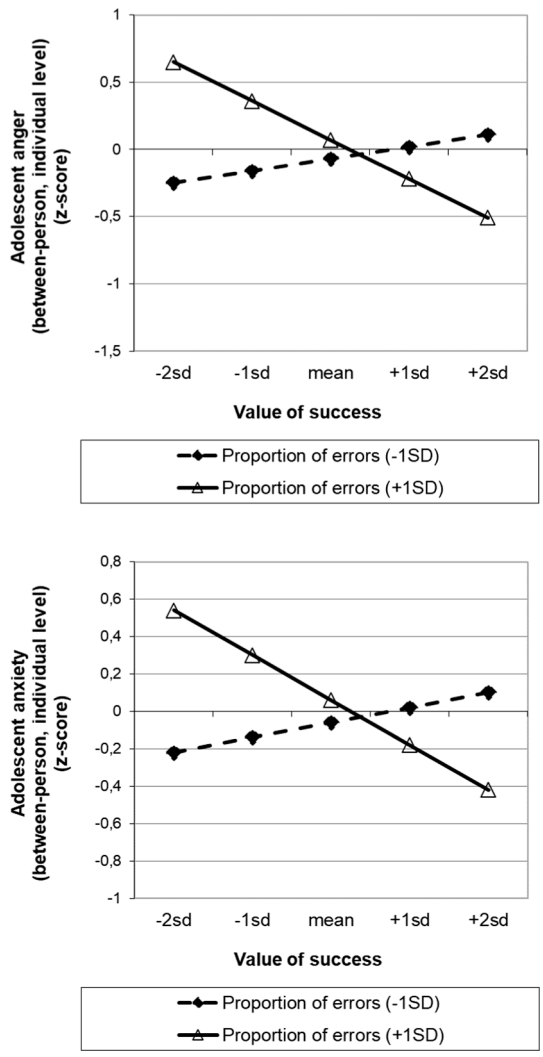


Fig. 5. Adolescent value of success as a moderator of the associations between the extent of errors and emotions: between amount of errors and anger (above), and between amount of errors and anxiety (below).

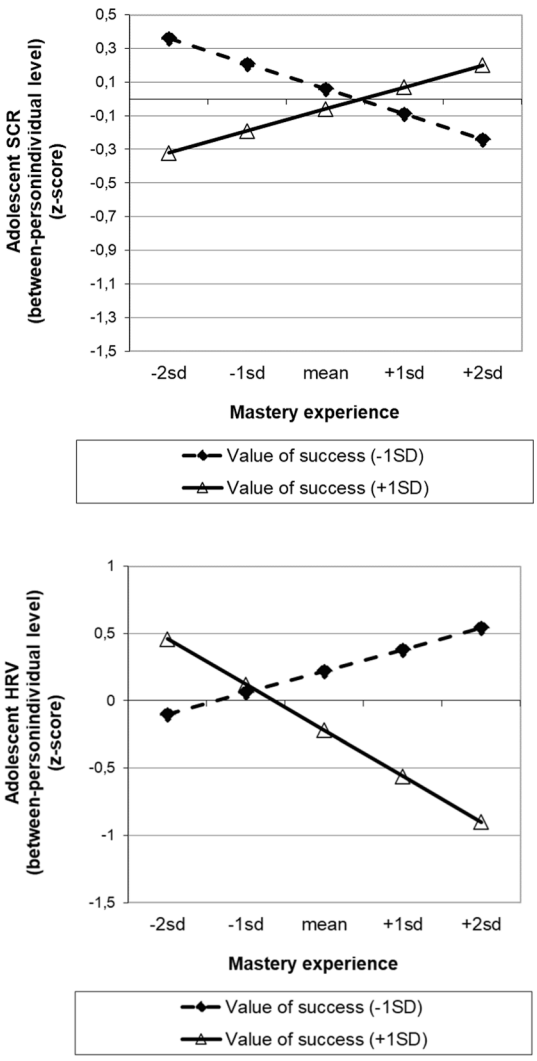


Fig. 6. Adolescent value of success as a moderator of the associations between mastery experience and psychophysiological states: between mastery experience and SCR (above), and between mastery experience and HRV (below).

models lacked power to detect significant interactions. Future studies would benefit from situational designs in which a larger number and a variety of different types of achievement situations would be nested within individuals. In general, more empirical research is needed for Value × Control interactions in different age groups, different types of situations, and contexts.

The results nevertheless showed that success value moderated the association of mastery experience with SCR and HRV at the within-person situational level, so that high success value combined with high mastery was related to increased SCR and decreased HRV. These findings are in line with Beh (1990) and Lackner et al. (2015), who showed in their experiments that HR increased and HRV decreased during task completion for university students and adults who had high efficacy beliefs and who attributed high importance of success. Performing well when adolescents highly value success may be related to adolescents' higher activation and alertness, which are also shown at the physiological level. However, the other part of the interpretation of the Value × Mastery interaction was that also low success value combined with low mastery was related to increased SCR and decreased HRV. One possible explanation for this finding is that perceived failure (low mastery) combined with helplessness and understating the importance of success activates the sympathetic nervous system. These are interesting and novel findings that are partly challenging to interpret and thus they warrant further research. Due to the relative lack of previous research, we had not set any a priori hypotheses for the predictions of ANS variables.

9. Limitations and Future directions

This study is not without limitations. First, although the present study investigated the role of learning experiences and task properties in adolescents' emotions and psychophysiological states in achievement situations, these were not authentic classroom situations. Hence, there is a need for future studies to examine similar mechanisms in actual classroom situations during various classroom activities and in various learning contexts. Quantitative studies should also be complemented with qualitative, mixed-method or single-subject designs in real-time learning settings in order to shed further light on students' learning experiences.

Second, although our study involved several different tasks (i.e., repeated situational measurements nested within individuals), we did not have a longitudinal cross-lagged design. Hence, causal conclusions about the directions of situational associations cannot be drawn. In addition, in our study the psychophysiological measures during the tasks were averaged separately for each task whereas self-reported emotions were requested immediately after the tasks (to avoid interfering with

task performance), which complicates the assumptions we can make about the direction of effects between emotions and physiological parameters. Future studies should investigate the reciprocal dynamics between learning experiences and task properties and adolescents' emotions and psychophysiological states both at between and within person levels. Further studies would also benefit from considering additional moderator variables and longer mediator chains to reveal causal ordering and possible feedback loops of learning experiences, emotions, and psychophysiological states.

Third, we used short measures to make the simulated achievement situations as authentic as possible when asking the same questions several times across different situations. Future studies would benefit from the use of longer scales that would enable more profound measurement of learning experiences and emotions, although keeping in mind how to motivate adolescents to fill the longer questionnaires carefully. There was also an asymmetry between some variables of learning experiences in terms of situational specificity. Mastery, challenge, and emotions were assessed as task-related variables, but value of success in math or reading as general variables. Future studies could replicate the findings with the symmetric designs. To extend our work it would also be useful to investigate a broader variety of emotions (e.g., pride, shame, curiosity) than was investigated in the present study.

Fourth, some of the investigated negative emotions, such as anger, anxiety and hopelessness also showed rather low group-level means during the achievement tasks. It is possible that the presented tasks were too brief to evoke strong negative emotions among the adolescents. Hence, the experimental situation might require stronger manipulation than was applied in the present study for these emotions to occur (in which case ethical issues would have to be considered.

Finally, although the socioeconomic background of our sample was rather representative of the same age Finnish population, students with learning difficulties were overrepresented and non-Finnish speaking students underrepresented in our sample due to the sampling procedure. In future studies, it would be valuable to examine similar mechanisms with more representative samples, in various clinical groups, in different age groups (younger and older learners and even among adults in various context such as out of college and workplace training settings) and with individuals from different educational and cultural systems (e.g., Latin America, Africa, or Middle Eastern contexts) to evaluate whether the findings can be replicated in various settings. Through such findings we would get evidence that the models tested are universal instead of being results of the current sample, only. In future studies it would also be valuable to investigate consequences for learning of various learning experiences and related positive and negative emotions and physiological states and different linear and nonlinear combinations of these.

10. Conclusion and practical implications

The results of our study were acquired in simulated achievement situations mimicking the true dynamics of "natural" situations. In general, they supported our schematic model (Fig. 1), which was informed by control-value theory of achievement emotions (Pekrun, 2006, 2017) and flow theory (Csikszentmihalyi, 2008; Csikszentmihalyi & Csikszentmihalyi, 1988; see also Schneider et al., 2016).

The results for the main effects showed that both learning experiences (value, mastery) and task properties (challenge) play a pivotal role in evoking emotions in achievement situations. Our study suggests that interventions to promote positive achievement emotions that target enhancing a sense of control and personal relevance are likely to be effective (see also Goetz et al., 2010).

Our results also suggest that aside of the main effects of learning experiences and task properties, it is also important to investigate interaction effects between them. High levels of mastery combined with high task challenge were found to be related to increased hope, whereas low levels of mastery combined with high task challenge were related to decreased enjoyment and increased anxiety, anger, hopelessness, and SCR during achievement situations. The results underscore the importance of paying attention to the relationship between individuals' skills and task demands, implying that tasks should be optimally challenging to stimulate positive activating emotions and reduce negative achievement emotions (see Spinath & Steinmayr, 2008; Vygotski, 1978). In turn, a low value of success combined with a high number of errors in the task was related to heightened levels of anger and anxiety. The results suggest that a low rather than a high level of personal relevance combined with struggling in the task tend to intensify negative achievement emotions.

Overall, the found within-person associations were generally stronger than those at the between-person level (see also Molenaar et al., 2004; Voelkle et al., 2014). In other words, situation-specific experiences played a remarkable role in experienced emotions and physiological states even after controlling for the effects of adolescent gender, task subject (math vs reading), and learning difficulties. These findings suggest that to maximize each students' learning potential, intervention efforts should be targeted at the characteristics of achievement and learning situations to help foster positive emotions and reduce negative ones. It may be possible to influence students' experiences and appraisals in achievement situations through curriculum planning, individualized instructional support, and stimulating learning environments.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This study forms part of the ongoing STAIRWAY-From Primary School to Secondary School Study. The study was funded by the grant from the Academy of Finland (#266851, #294970).

References

Ahmed, W., Minnaert, A., Werf, G., & Kuyper, H. (2010). The role of competence and value beliefs in students' daily emotional *experiences: A multilevel test of a transactional model. Learning and Individual Differences, 20*, 507–511.

Bandura, A. (1997). *Self-efficacy. The exercise of control.* New York: W.H. Freeman.

Barrett, L. F. (2006). Are emotions natural kinds? *Perspectives on Psychological Science, 1*, 28–58.

Beauchaine, T. P. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Developmental Psychopathology, 13*, 183–214.

Beauchaine, T. P., & Cicchetti, D. (2019). Emotion dysregulation and emerging psychopathology: A transdiagnostic, transdisciplinary perspective. *Development and Psychopathology, 31*, 799–804.

Beh, H. C. (1990). Achievement motivation, performance and cardiovascular activity. *International Journal of Psychophysiology, 10*, 39–45.

Berntson, G. G., et al. (1991). Autonomic determinism: The modes of autonomic control, the doctrine of autonomic space, and the laws of autonomic constraint. *Psychological Review, 98*, 459–487.

Berntson, G. G., Bigger, J.r., Eckberg, D. L., Grossman, P., Kaufman, P. G., Malik, M., et al. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology, 34*, 623–648.

Benedek, M., & Kaernbach, C. (2010). Decomposition of skin conductance data by means of nonnegative deconvolution. *Psychophysiology, 47*, 647–658.

Bieg, M., Goetz, T., & Hubbard, K. (2013). Can I master it and does it matter? An intraindividual analysis on control–value antecedents of trait and state academic emotions. *Learning and Individual Differences, 28*, 102–108.

Boekaerts, M. (2001). Activated motivational beliefs, current concerns and emotional arousal.In S. Volet & S. Järvelä (Eds.), *Motivation in learning contexts: Theoretical advances andmethodological implications* (pp. 17–32). Elmsford, NY: Pergamon Press.

Boucsein, W. (2012). *Electrodermal activity*. New York: Springer.

Clem, A.-L., Hirvonen, R., Aunola, K., & Kiuru, N. (2021). Reciprocal relations between adolescents' self-concepts of ability and achievement emotions in mathematics and literacy. *Contemporary Educational Psychology, 65*, Article 101964.

Crowell, S. E., Baucoma, B. R., Yaptangcoa, M., Bridea, D., Hsiaob, R., McCauley, E., et al. (2014). Emotion dysregulation and dyadic conflict in depressed and typical

adolescents: Evaluating concordance across psychophysiological and observational measures. *Biological Psychology, 98*, 50–58.
Csikszentmihalyi, M. (2008). *Flow: The psychology of optimal experience*. New York: Harper Perennial.
Csikszentmihalyi, M., & Csikszentmihalyi, I. (1988). *Optimal experience, psychological studies of flow in consciousness*. Cambridge: Cambridge University Press.
Delle Fave, A., & Massimini, F. (2005). The investigation of optimal experience and apathy. *European Psychologist, 4*, 264–274.
Dettmers, S., Trautwein, U., Ludtke, O., Goetz, T., Frenzel, C., & Pekrun, R. (2011). Students' emotions during homework in mathematics: Testing a theoretical model of antecedents and achievement outcomes. *Contemporary Educational Psychology, 36*, 25–35.
Dweck, C. (2006). *Mindset: The new psychology of success*. New York: Random House.
Eccles, J., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J. L., et al. (1983). Expectancies, values, and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motivation* (pp. 75–146). San Francisco, CA: W.H. Freeman.
Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist, 56*, 218–226.
Frenzel, A. C., Pekrun, R., & Goetz, T. (2007). Girls and mathematics—A "hopeless'' issue? A control-value approach to gender differences in emotions towards mathematics. *European Journal of Psychology of Education, 22*(4), 497–514.
Fujita, F., Diener, E., & Sandvik, E. (1991). Gender differences in negative affect and well-being: The case for emotional intensity. *Journal of Personality and Social Psychology, 61*, 427–434.
Goedhart, A. D., Van Der Sluis, S., Houtveen, J. H., Willemsen, G., & Geus, E. J. C. (2007). Comparison of time and frequency domain measures of RSA in ambulatory recordings. *Psychophysiology, 44*, 203–215.
Goetz, T., Frenzel, C. A., Hall, N. C., & Pekrun, R. (2008). Antecedents of academic emotions: Testing the internal/external frame of reference model for academic enjoyment. *Contemporary Educational Psychology, 33*, 9–33.
Goetz, T., Bieg, M., Ludtke, O., Pekrun, R., & Hall, N. C. (2013). Do girls really experience more anxiety in mathematics? *Psychological Science, 24*, 2079–2087.
Goetz, T., Frenzel, A. C., Stoeger, H., & Hall, N. C. (2010). Antecedents of everyday positive emotions: An experience sampling analysis. *Motivation and Emotion, 34*(1), 49–62.
Heck, R. H., & Thomas, S. L. (2015). An introduction to multilevel modeling techniques: MLM and SEM approaches using Mplus. *Routledge*.
Inkinen, M., Lonka, K., Hakkarainen, K., Muukkonen, H., Litmanen, T., & Salmela-Aro, K. (2014). The interface between core affects and the challenge-skill relationship. *Journal of Happiness Studies, 15*, 891–913.
Kanerva, K., Kiistala, I., Kalakoski, V., Hirvonen, R., Ahonen, T., & Kiuru, N. (2019). The feasibility of working memory tablet tasks in predicting scholastic skills in classroom settings. *Applied Cognitive Psychology, 33*, 1224–1237.
Ketonen, E., Dietrich, J., Moeller, J., Salmela-Aro, K., & Lonka, K. (2018). The role of daily autonomous and controlled educational goals in students' academic emotion states: An experience sampling method approach. *Learning and Instruction, 53*, 10–20.
Ketonen, E. E., Malmberg, L.-E., Salmela-Aro, K., Muukkonen, H., Tuominen, H., & Lonka, K. (2019). The role of study engagement in university students' daily experiences: A multilevel test of moderation. *Learning and Individual Differences, 69*, 196–205.
Kiuru, N., Eklund, K., Hirvonen, R., Kaartinen, J., Mikkonen, J., & Ahonen, T. (2014). Emotions in achievement situations (EAS) scale. Department of Psychology, University of Jyväskylä.
Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology, 84*, 394–421.
Kreibig, S. D., & Gendolla, G. H. E. (2014). Autonomic nermous system measurement of emotion in education and achievement settings. In R. Pekrun, & L. Linnenbrink-Garcia (Eds.), *International Handbook of Emotions in Education* (pp. 625–642). New York, US: Routledge/Taylor & Francis Group.
Lackner, H. K., Gramer, M., Paechter, M., Wimmer, S., Hinghofer-Szalkay, H., & Papousek, I. (2015). Academic goal orientation and cardiovascular reactivity in a performance situation. *Applied psychophysiology and biofeedback, 40*(3), 189–200.
Lampinen, E., Karolaakso, T., Karvonen, A., Kaartinen, J., Kykyri, V.-L., Seikkula, J., et al. (2018). Electrodermal activity, respiratory sinus arrhythmia, and heart rate variability in a relationship enrichment program. *Mindfulness, 9*, 1076–1087.
Landerl, K., Wimmer, H., & Moser, E. (1997). *Salzburger Leseund rechtschreibtest [Salzburg Reading and Spelling Test]*. Bern, Switzerland: Hans Huber.
Lehikoinen, A., Ranta-Nilkku, E., Mikkonen, J., Kaartinen, J., Penttonen, M., Ahonen, T., et al. (2019). The role of adolescents' temperament in their positive and negative emotions as well as psychophysiological reactions during achievement situations. *Learning and Individual Differences, 69*, 116–128.
Levenson, R. W. (2014). Autonomic nervous system and emotion. *Emotion Review, 6*, 100–112.
Lindeman, J. (1998). ALLU—Ala-asteen lukutesti [ALLU—Reading test for primary school]. Turku: University of Turku, Finland: The Center for Learning Research.
Linnenbrink, E. A., & Pintrich, P. R. (2002). Achievement goal theory and affect: An asymmetrical bidirectional model. *Educational Psychologist, 37*, 69–78.
Malmberg, L.-E., Walls, T. A., Martin, A. J., Little, T. D., & Lim, W. H. T. (2013). Primary school students' learning experiences of, and self-beliefs about competence, effort, and difficulty: Random effects models. *Learning and Individual Differences, 28*, 54–65.
Mauss, I. B., & Robinson, M. D. (2009). Measures of emotion: A review. *Cognition and Emotion, 23*, 209–237.
McManis, M. H., Bradley, M. M., Berg, W. K., Cuthbert, B. N., & Lang, P. J. (2001). Emotional reactions in children: Verbal, physiological, and behavioral responses to affective pictures. *Psychophysiology, 38*(2), 222–231.
Moneta, G., & Csikszentmihalyi, M. (1996). The effect of perceived challenges and skills on the quality of subjective experience. *Journal of Personality, 64*, 275–310.
Moeller, J., Bracketta, M. A., Ivcevica, Z., & White, A. E. (2020). High school students' feelings: Discoveries from a large national survey and an experience sampling study. *Learning and Instruction, 66*, Article 101301.
Muthén, L., & Muthén, B. O. (1998–2021). Mplus Version 8.4 & Mplus users' guide, Los Angeles, CA: Muthén and Muthén. http://www.statmodel.com.
Nesselroade, J. R., & Molenaar, P. C. (2016). Some behavioral science measurement concerns and proposals. *Multivariate Behavioral Research, 51*(2–3), 396–412.
Official Statistics of Finland. (2016a). *Educational structure of population* [E-publication]. Helsinki,: Statistics Finland. Retrieved November 19, 2015, from www.stat.fi/til/vkour/2014/vkour_2014_2015-11-05_tie_001_en.html.
Official Statistics of Finland. (2016b). *Families*. Appendix Table 3: Families with underage children by type in 1950–2014 [E-publication]. Helsinki: Statistics Finland. Retrieved November 19, 2015, from www.stat.fi/til/perh/2014/perh_2014_2015-05-28_tau_003_en.html.
Pekrun, R. (2000). A social-cognitive, control-value theory of achievement emotions. In J. Heckhausen (Ed.), *Motivational psychology of human development* (pp. 143–163). Oxford: Elsevier.
Pekrun, R. (2006). The control–value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*, 315–341.
Pekrun, R. (2017). Emotion and achievement during adolescence. *Child Development Perspectives, 11*, 215–221.
Pekrun, R., Goetz, T., Frenzel, A. C., Barchfeld, P., & Perry, R. P. (2011). Measuring emotions in students' learning and performance: The Achievement Emotions Questionnaire (AEQ). *Contemporary Educational Psychology, 36*, 36–48.
Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational Psychologist, 37*, 91–105.
Penttila, J., Helminen, A., Jartti, T., Kuusela, T., Huikuri, H. V., Tulppo, M. P., et al. (2001). Time domain, geometrical and frequency domain analysis of cardiac vagal outflow: Effects of various respiratory patterns. *Clinical Physiology, 21*, 365–376.
Pintrich, P. R. (2000). Multiple goals, multiple pathways: The role of goal orientation in learning and achievement. *Journal of Educational Psychology, 92*, 544–555.
Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology, 74*, 116–143.
Posada-Quintero, H. F., & Chon, K. H. (2020). Innovations in electrodermal activity data collection and signal processing: A systematic review. *Sensors, 20*(2).
Putwain, D. W., Pekrun, R., Nicholson, L. J., Symes, W., Becker, S., & Marsh, H. W. (2018). Control-value appraisals, enjoyment, and boredom in mathematics: A longitudinal latent interaction analysis. *American Educational Research Journal, 55*(6), 1339–1368.
Rosenstreich, E., Feldman, D. B., Davidson, O. B., Maza, E., & Margalit, M. (2015). Hope, optimism and loneliness among first-year college students with learning disabilities: A brief longitudinal study. *European Journal of Special Needs Education, 30*, 338–350.
Russell, J. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology., 39*(6), 1161–1178.
Russell, J. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110*, 145–172.
Räsänen, P., Salminen, J., Wilson, A. J., Aunio, P., & Dehaene, S. (2009). Computer assisted intervention for children with low numeracy skills. *Cognitive Development, 24*, 450–472.
Sainio, P., Eklund, K., Ahonen, T., & Kiuru, N. (2019). The role of learning difficulties in adolescents' academic emotions and academic achievement. *Journal of Learning Disabilities, 52*, 287–298.
Salmela-Aro, K., & Upadyaya, K. (2014). School burnout and engagement in the context of demands-resources model. *British Journal of Educational Psychology, 84*(1), 137–151.
Schmitz, B., & Skinner, E. (1993). Perceived control, effort, and academic performance: Interindividual, intraindividual, and multivariate timeseries analyses. *Journal of Personality and Social Psychology, 64*, 1010–1028.
Schneider, B., Krajcik, J., Lavonen, J., Salmela-Aro, K., Broda, M., Spicer, J., et al. (2016). Investigating Optimal Learning Moments in U.S. and Finnish Science Classes. *Journal of Research in Science Teaching, 53*, 400–421.
Seligman, M. E. P., & Csikszentmihalyi, M. (2000). Positive psychology: An introduction. *American Psychologist, 55*(1), 5–14.
Shao, K., Pekrun, R., Marsh, H. W., & Loderer, K. (2020). Control-value appraisals, achievement emotions, and foreign language performance: A latent interaction analysis. *Learning and Instruction, 69*, Article 101356.
Shernoff, D. J., Csikszentmihalyi, M., Schnelder, B., & Shernoff, E. S. (2003). Student engagement in high school classrooms from the perspective of flow theory. *School Psychology Quarterly, 18*(2), 158–176.
Spinath, B., & Steinmayr, R. (2008). Longitudinal analysis of intrinsic motivation and competence beliefs: Is there a relation over time? *Child Development, 79*, 1555–1569.
Tanaka, A., & Murayama, K. (2014). Within-person analyses of situational interest and boredom: Interactions between task-specific perceptions and achievement goals. *Journal of Educational Psychology, 106*, 1122–1134.
Tolvanen, A., Kiuru, N., Leskinen, E., Hakkarainen, K., Inkinen, M., Lonka, K., et al. (2011). A new approach for estimating a nonlinear growth component in multilevel modeling. *International Journal of Behavioral Development, 35*, 370–379.
Venables, L., & Fairclough, S. H. (2009). The influence of performance feedback on goal-setting and mental effort regulation. *Motivation and Emotion, 33*(1), 63–74.

Voelkle, M. C., Brose, A., Schmiedek, F., & Lindenberger, U. (2014). Toward a unified framework for the study of between-person and within-person structures: Building a bridge between two research paradigms. *Multivariate Behavior Research, 49*, 193–213.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54*, 1063–1070.

Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of motivation. *Contemporary Educational Psychology, 25*, 68–81.

Wigfield, A., & Cambria, J. (2010). Students' achievement values, goal orientations, and interest: Definitions, development, and relations to achievement outcomes. *Developmental Review, 30*, 1–35.