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Investigating the Relationship Between Boredom and Creativity: The Role of Academic Challenge

Maike Krannich [1], Basak Calik [2], Thomas Goetz [3], Anna-Lena Ullrich [4] and Anastasiya Lipnevich [5,*]

[1] Department of Psychology, University of Zurich, CH-8050 Zurich, Switzerland; maike.krannich@uzh.ch
[2] Department of Educational Sciences, Istanbul Medeniyet University, 34720 Istanbul, Turkey; basak.calik@medeniyet.edu.tr
[3] Department of Developmental and Educational Psychology, Faculty of Psychology, University of Vienna, Universitaetsstr. 7, A-1010 Vienna, Austria; thomas.goetz@univie.ac.at
[4] Institute of Digital and Computer Science Education, St. Gallen University of Teacher Education, 9000 St. Gallen, Switzerland; anna-lena.ullrich@phsg.ch
[5] Queens College and the Graduate Center, City University of New York, Queens, NY 11367-1597, USA
* Correspondence: alipnevich@qc.cuny.edu

Abstract: This study examined the boredom–creativity link by including students' levels of over- and underchallenge. Based on the Meaning and Attentional Components model and the Cognitive Load Theory, we proposed the negative effects of students' boredom combined with being overchallenged on creativity, whereas boredom combined with being underchallenged might enhance creativity. We examined this hypothesis in mathematics classes in a sample of N = 119 German high school students (M_{age} = 13.86, grade 8). A random slope approach to interaction modeling was used to investigate the effects of boredom and overchallenge and of boredom and underchallenge. The results revealed significant interaction effects in the postulated directions and no conditional effects neither of boredom nor of over- or underchallenge on the first creativity task. Hence, higher levels of boredom combined with higher underchallenge were related to increased mathematical creativity, whereas higher boredom combined with higher overchallenge reduced creativity on the first task but not on tasks two and three. The study provides insights into how cognition and emotion interact regarding learning and creative behavior and offers practical implications for understanding how students experience boredom, particularly in relation to being either over- or underchallenged. This understanding can clarify the attentional and motivational consequences of this prevalent emotion, especially in mathematics.

Keywords: boredom; creativity; mathematics; level of challenge; MAC model

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1. Educational Relevance Statement

This study sheds light on the interaction between high-school students' level of challenge and their boredom during mathematics class, investigating its impact on mathematical creativity tasks. Given the various detrimental effects of boredom on educational outcomes, together with some other studies reporting positive links of boredom with creativity, the results of our study give a first indication that the proposed positive effects of boredom on creative tasks might only occur in case of students being bored and underchallenged.

Boredom is one of the most frequently reported emotions in the classroom, with numerous reported detrimental effects on learning and achievement (e.g., Pekrun et al., 2010; Camacho-Morles et al., 2021; Goetz et al., 2024). However, theoretical considerations exist that view boredom as being positively related to performance in creative tasks due to students' attempts to seek stimulation in boring situations (e.g., Craven & Frick, 2024; Elpidorou, 2014). Empirical evidence for the positive link between boredom and creativity is contradictory, with some results supporting a positive connection (Gasper & Middlewood, 2014; Mann & Cadman, 2014; Schubert, 1977, 1978), whereas others (Larson, 1990; Haager et al., 2016) rejected this link or even supported negative correlations between the two constructs.

We aim to contribute to this research by examining boredom in conjunction with over- and underchallenge, as both may play a pivotal role in the boredom–creativity link, particularly in relation to performance on creative tasks. We investigate creativity and boredom in the context of mathematics classrooms. The fluctuating intensity of emotions across various domains demands a thorough examination of this construct from a domain-specific perspective (e.g., Goetz et al., 2006). The results from the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) highlight the significance of emotions in mathematics (e.g., Organization for Economic Co-Operation and Development [OECD], 2023). Notably, Camacho-Morles et al.'s (2021) meta-analysis demonstrates that the relationship between emotions and academic performance is markedly stronger in mathematics compared to other domains, such as science and literacy. In mathematics classes, students frequently experience boredom (e.g., Pekrun et al., 2002), which is characterized by an aversive experience of "dissatisfaction with the available stimuli" (Fenichel, 1951, p. 349) provided by the environment. Thus, bored students may want to engage in satisfying tasks but do not have the ability to do so (Eastwood et al., 2012). This dissatisfaction during mathematics classes occurs either in the case of cognitively very demanding or cognitively very undemanding situations (i.e., over- or underchallenge, Acee et al., 2010; Fenichel, 1951; Krannich et al., 2022) with presumably different consequences on performance on mathematical creativity tasks (Krannich & Goetz, 2021; van Tilburg & Igou, 2012). The underlying mechanisms may vary. When bored and underchallenged during mathematics classes, students seek cognitive stimulation by combining different thoughts related to the task or thinking outside the box. On the other hand, when bored and overchallenged, students escape in less demanding thoughts being unrelated to mathematics, and cognitive resources to set one's attentional focus back to the mathematical creativity tasks are lacking (Goetz et al., 2023; Westgate & Wilson, 2018). Thus, boredom in the domain of mathematics might set the stage for new creative thoughts by broadening one's attentional focus (Kasof, 1997; van Tilburg & Igou, 2012), but only if there are cognitive resources available (Kahneman, 1973; Sweller et al., 1998). Hence, boredom may evoke creativity in underchallenging but not in overchallenging situations. To our knowledge, this is the first study looking at boredom–creativity contingencies while taking into account students' level of challenge.

2. Boredom at School

Boredom at school is a commonly experienced achievement emotion (Pekrun, 2006; Pekrun et al., 2023) that comprises a unique combination of affective (experienced as negative and aversive), cognitive (dilatation of time), motivational (desire to escape from of modify situation), physiological (mostly reduced arousal), and expressive components (Fisher, 1993; Harris, 2000; Mikulas & Vodanovich, 1993; Scherer, 2000; Vodanovich & Watt, 2016). Attentional theories state that boredom is closely linked to attentional difficulties (e.g., Danckert et al., 2018; Eastwood et al., 2012) and occurs in situations of a mismatch between cognitive demands or environmental stimulation and available mental resources, that is, student over- and underchallenge (Carriere et al., 2008; Danckert & Merrifield, 2016; Daschmann et al., 2011; Eastwood et al., 2012; Westgate & Wilson, 2018; Struk et al., 2021).

In a school context, studies have shown that boredom is domain-specific (Goetz et al., 2006) and one of the most frequently experienced emotions overall (e.g., Moeller et al., 2020), being particularly high in mathematics classes (Goetz et al., 2014; Pekrun et al., 2002). Boredom has negative consequences on numerous outcomes such as achievement, stress, and higher drop-out rates (for overviews see Camacho-Morles et al., 2021; Goetz et al., 2019) but theoretical considerations lead to the assumption that boredom might also be connected to stimulation seeking and enhanced creativity under specific circumstances (Brissett & Snow, 1993; Toohey, 2011; Vodanovich, 2003).

3. Mathematical Creativity

Creativity is a complex construct that has a plethora of definitions (e.g., Balka, 1974; Collard & Looney, 2014; Davis, 2009; Green et al., 2023; Isen, 1999; Kozbelt et al., 2010). The core element of all these definitions is the generation of new ideas (Amabile, 1996; Davis, 2009; Runco & Chand, 1995) that may be influenced by visualizing and mental manipulation of abstract concepts and spatial reasoning (Commodari et al., 2024). Thereby, the creative problem-solving process includes three different aspects: *fluency* in the production of ideas, *originality* and uniqueness of these ideas, and *flexibility* in this idea generation (Davis (2009), Leikin and Lev (2013), Runco and Acar (2012); see also the definition of mathematical creativity of Livne (1999) and Wagner and Zimmermann (1986)).

Mathematical creativity can be considered as a domain-specific concept (e.g., Haylock, 1987; Huang et al., 2017; Kattou et al., 2015; Lee et al., 2003; Silver, 1997), which lies in the heart of advanced mathematics and is therefore a very important ability (e.g., Bennevall, 2016; Sriraman, 2009). In a broad sense, mathematical creativity is defined as the ability of divergent and original thinking in the field of mathematics (e.g., perceiving original patterns and relationships; Wagner & Zimmermann, 1986). More specifically, mathematical creativity is defined as the individuals' specific ability to generate mathematics-related ideas, solutions, or insights that are both *new and original* and *effective* (Kaufman (2009), Runco and Jaeger (2012); for the original conceptualization, see Barron (1955) and Stein (1953)). The latter aspect refers to the worthiness, appropriateness, and inherent value of problem-solving and is frequently ignored when intuitively thinking about mathematical creativity.

4. Links Between Boredom and Creativity

Theoretical considerations and empirical results regarding the connection between boredom and creativity are ambiguous. Theoretically, positive effects of boredom on performance on creative tasks are postulated in the literature (e.g., 1975/2000; Elpidorou, 2014; Schubert, 1977, 1978; Vodanovich, 2003). This assumption is primarily based on the fact that in boring situations, a shift of attention from the current situation to new stimuli may take place, accompanied by one's search for meaning (Eastwood et al., 2012; van Tilburg & Igou, 2012; Vodanovich, 2003). In the absence of external stimuli, attention is focused on internal processes and thoughts (Mann & Cadman, 2014), thus generating new ideas (e.g., Belton & Priyadharshini, 2007; Sio & Ormerod, 2009). The empirical results of an experimental study by Mann and Cadman (2014) showed that subjects who were induced to be bored during a writing task produced a higher number of creative solutions in the subsequent divergent problem-solving task. In addition to this result, Gasper and Middlewood (2014) showed positive correlations of experimentally induced boredom with associative thoughts in three experiments that used different instruments to measure individuals' ability to produce associative and novel thoughts. Similarly, Park et al. (2019) also confirmed the fostering role of boredom on undergraduate students' creativity in producing unique ideas even after controlling for their positive and negative moods.

Contrasting these results, other research provided initial evidence demonstrating that boredom at school is a clearly negative aversive emotion (e.g., Camacho-Morles et al., 2021; Pekrun et al., 2010) and therefore should not be positively related to enhanced creativity. This is in line with the broaden-and-build theory of positive emotions (Fredrickson, 2001; Fredrickson & Branigan, 2005) supporting the superiority of positive emotions compared to negative emotions such as boredom when it comes to the production of creative responses (e.g., Grawitch et al., 2003; Hirt et al., 2008; for a meta-analysis see Baas et al., 2008). Consistent with these results, Larson (1990) assessed students' self-perceived boredom during an essay-writing task and found negative relations of boredom with the originality of and overall performance on the writing task. Additionally, Haager et al. (2016) investigated relations between boredom and performance on several consecutive semantic generation tasks, revealing a clearly negative relation between boredom and the fluency of creative task performance when accounting for task practice. Nettinga et al. (2023) also examined the relations between trait and state boredom and creativity across two experiments. The first experiment was a partial replication of Mann and Cadman's (2014) study. Contrary to the findings of Mann and Cadman (2014), a negative relation was revealed between individuals' state boredom and divergent thinking. Additionally, trait boredom was negatively linked to self-beliefs of creativity and individuals' engagement in everyday creative behaviors. Furthermore, the second experiment revealed no relation between either state or trait boredom and creativity reflected by the originality and uniqueness of a novel creativity task.

Summarizing theoretical and empirical findings when it comes to links between boredom and creativity, the results are inconsistent and often contradictory. Recently, Zeißig et al. (2024) conducted a scoping review that systematically analyzed definitions, methodological characteristics, and empirical results concerning the relationship between boredom and creativity in educational contexts. Their findings unequivocally demonstrate the inconsistency in research, revealing both positive and negative associations between boredom and creativity. To gain a clearer insight into the connection between boredom and creativity, it is essential to consider how academic challenge relates to boredom. Acee et al. (2010) investigated academic boredom in general among college students in both underchallenging and overchallenging situations. Their findings confirmed that boredom is a complex construct that varies depending on the context. In overchallenging situations, students distinguished between two types of boredom: task-focused boredom, which arises from the tediousness and meaninglessness of the task, and self-focused boredom, marked by feelings of dissatisfaction and frustration. In contrast, in underchallenging situations, students did not differentiate between types of boredom. Therefore, we suggest having a closer look at boredom in mathematics in combination with either over- or underchallenge: Both have been shown to be closely intertwined with boredom, and it is safe to assume that the resulting boredom will differentially relate to performance on mathematical creativity tasks.

Underchallenged students have cognitive resources at their disposal, and these resources can be considered as a necessary but not sufficient prerequisite of the production of creative thoughts (Groborz & Necka, 2003; Zabelina & Robinson, 2010). Importantly, cognitive resources alone can be used in various ways, but in combination with boredom, it might result in an active increase in broadened attention and individuals' search for cognitive stimulation through creative thoughts (e.g., Bench & Lench, 2013; Fredrickson, 2001; Rowe et al., 2007). In this case, the motivational consequence of boredom results in the attempt to re-engage into the momentary situation (approach motivation), for example, by combining different task-related thoughts (e.g., Carriere et al., 2008; Eastwood et al., 2012; Nett et al., 2010). On the other hand, when students are overchallenged, cognitive resources are depleted and motivational consequence of boredom can be a complete cognitive drift-off to less stimulating cognitively undemanding thoughts without the motivation to re-engage and set the attentional focus back to the task (e.g., Kahneman, 1973; Mann & Cadman, 2014; Mercer-Lynn et al., 2014; Smallwood & Schooler, 2006; Struk et al., 2021). Importantly, the undemanding thoughts themselves (e.g., thinking about what one could eat for lunch) in case of being overchallenged are not useful for enhancing performance on the mathematical creativity tasks, as new creative thoughts have to be, by definition, not only original but also effective (for a detailed discussion of this two-fold aspect of creativity see Runco & Jaeger, 2012). In summary, the combination of boredom and overchallenge might result in negative effects on performance on mathematical creativity tasks, and the opposite pattern may be true for combined boredom and underchallenge.

This is in line with the Meaning And Attentional Components (MAC) model of boredom from Westgate and Wilson (2018), which shows that overstimulation in combination with boredom leads to individuals' motivational attempts to decrease demands, and understimulation combined with boredom may result in an intended increase in demands. Specifically, the meaning component distinguishes between low meaning when the task conflicts with valued goals and high meaning when the task aligns with valued goals. Additionally, the attention component clearly distinguishes between four states: understimulation occurs when the demands are less than the cognitive resources available; low-level engagement signifies a scenario of both low demand and low resources; high-level engagement arises when demand and resources are both high; and overstimulation happens when the resources fall short of the demands. In this regard, high meaning leads to boredom when paired with being under- or overchallenged (Goetz et al., 2024). Similarly, the Cognitive Load Theory (CLT; Sweller, 1988) further supports this assumption, under the condition of an overchallenge task demanding the imposition of a very high working memory load, with the opposite being the case when students feel underchallenged (Sweller, 1988; Sweller et al., 1998). It therefore seems plausible that bored students experiencing a mental overload in mathematics classes should first, have fewer resources to work on mathematical creativity tasks, and second, the motivational consequence results in the wish to decrease cognitive load. On the other hand, when underchallenged in mathematics classes, students will have enough cognitive resources left to utilize toward finding creative solutions to mathematical problems. Importantly, underchallenged students do not necessarily make use of these concomitant cognitive resources, but the combination with boredom induces the search for meaningfulness and a state of equilibrium through additional cognitive stimulation by a broadened way of thinking. Therefore, underchallenge combined with boredom might enhance cognitive associative and creative thoughts (Csikszentmihalyi, 2014; Eastwood et al., 2012; Kasof, 1997; Krannich & Goetz, 2021; Mikulas & Vodanovich, 1993; Westgate & Wilson, 2018).

Summarizing these theoretical contentions, we suggest differential effects of boredom in mathematics on mathematical creativity when combined with over- or underchallenge, which has been ignored so far. Our study attempted to fill this gap and examine links among boredom and creativity in mathematics classes of students being over- and underchallenged. By exploring these dynamics, the research will enhance the understanding of how boredom influences attention and motivation, particularly in mathematics. This knowledge may lead to practical implications, helping educators tailor learning experiences to better engage students and foster vibrant educational environments.

5. The Present Study and Hypotheses

The current study examined students' boredom in mathematics classes as well as performance on mathematical creativity tasks. We attempted to reconcile existing inconsistent findings by including students' challenges—a variable that is closely and differentially related to students' boredom. Primarily based on Westgate and Wilson's (2018) MAC-model of boredom together with Sweller's (1988) Cognitive Load Theory, we hypothesized that a higher level of mathematics-related boredom in combination with a higher level of overchallenge is negatively connected with performance on mathematical creativity tasks, whereas boredom in combination with a higher level of underchallenge is positively connected with performance on mathematical creativity tasks.

6. Method

6.1. Ethical and Transparency Statement

Data collection, data protection, and ethical issues of the present study were handled according to the guidelines of the German Association for Psychology (Deutsche Gesellschaft für Psychologie (DGPs) [German Association of Psychology] (2019)) and the American Psychological Association (2020). The study was conducted in compliance with ethical standards expressed in the WMA Declaration of Helsinki, and all study procedures were deemed appropriate by the Institutional Review Board of the University of (Include blinded institutional name here). The study was noninvasive, and no issues concerning a threat to human health, well-being, or dignity (including issues of data protection) were identified. Student participation was voluntary, parents provided informed consent, and data analyses were conducted on anonymous data.

A former version of this manuscript, including the presented sample, study procedure, and results, was part of a dissertation (Krannich, 2019).

6.2. Sample and Procedure

The sample consisted of $N = 119$ German students from six different classes and three schools. Students were in eighth grade, had a mean age of $M = 13.86$ years ($SD = 0.55$), and attended the highest track of the German school system (i.e., Gymnasium; over 40% of the total student cohort in Germany attend this track; Statistisches Bundesamt [Federal Statistical Office], 2020). This school track and specifically eighth graders have been chosen as a previous study showed that those high-achieving students of a similar age group experienced not only over- but also underchallenge in mathematics classes, which is a central aspect for our study (e.g., Krannich et al., 2019). Overall, 42% of the students were female, and 88.2% reported their nationality as German. All students participated in the study on a voluntary and confidential basis. Boredom in mathematics and over- and underchallenge together with mathematical creativity and demographic data were assessed during a mathematics class via a standardized questionnaire, and students were asked to complete three mathematical creativity tasks. At the beginning of the mathematics class, students first reported their grades in mathematics. During mathematics classes, students reported their momentary boredom and challenge followed by further performance indicators together with demographic data. At the very end of the class, three different mathematical creativity tasks were presented to the participants. To avoid any influence of the sequencing of the tasks, we rotated the order of presenting the tasks, and the students were randomly assigned to one of the six resulted test booklets. The students worked for 15 min on these tasks and completed all of them in an open-ended format to enable them to freely produce every possible answer to the three given problems.

6.3. Study Measures

Assessment of academic boredom. Boredom in mathematics was assessed with six items from the Achievement Emotions Questionnaire (AEQ; see Pekrun et al., 2011), covering the different components of boredom (e.g., affective: "I think the mathematics class is boring", motivational: "I'm so bored that I feel like leaving the classroom", physiological: "I feel restless cause I'm waiting for the mathematics class to end", and cognitive: "My mind repeatedly begins to wander"; Scherer, 2000; Scherer & Moors, 2019). Items were rated on a five-point Likert scale, ranging from 1 (*strongly disagree)* to 5 (*strongly agree)*.

Assessment of mathematics-related over- and underchallenge. Subject-specific over- and underchallenge was assessed with two items asking how students perceived the demands of their mathematics classes on a five-point Likert scale bounded by 1 (*completely disagree*) to 5 (*completely agree*; "I feel underchallenged in mathematics classes" and "I feel overchallenged in mathematics classes", respectively). We furthermore assessed students' grades on their last mathematics exam on a scale bounded by 1 (the best possible grade in the German school system) to 6 (the worst possible grade in the German school system). The level of overchallenge was then represented by students' self-perceived overchallenge and their last grade with higher values indicating poorer performance, hence a higher overchallenge. On the contrary, higher underchallenge was represented by students' self-perceived underchallenge and again their last grade, which was reported in this case. This procedure was chosen; as first, numerous studies showed self-assessments of challenge and ability as being highly prone to biases, especially in the direction of overestimation of one's performance (e.g., Ackerman & Wolman, 2007; Brown, 2012; Gonyea, 2005; Sedikides & Strube, 1997). As such, we did not want to solely rely on our analyses on self-perceived measures of challenge. Second, the assessment of grade alone was not sufficient to gauge students' level of underchallenge as a very good grade might also be an indicator of optimal challenge.

Assessment of mathematical creativity. We included three different mathematics-related creativity tasks into our study (see Supplementary SA for the three tasks). The tasks were adapted and translated from Balka's (1974) Creative Ability in Mathematics Test (CAMT), specifically being developed for middle grade students and being the only instrument we found that included all three aspects of the creative process (i.e., fluency, originality, and flexibility) and additionally extensively discussed reliability and validity problems (Mann, 2005). All three tasks were open-ended and had a reference to mathematics but did not test for specific mathematical knowledge (e.g., stochastic theory or linear functions/equation systems). In Task 1, the participating students had to list as many things as possible that could happen when the number of sides of a polygon increases; in Task 2, they had to produce ideas about geometrical shapes if they were to be drawn on curved surfaces; and in Task 3, two hidden geometric figures had to be found by suggesting as many problems as possible, which had to be solved in order to identify these figures. Hence, all three tasks are in some way embedded into a geometry context but do not require specific geometric or other mathematical knowledge.

Scoring procedure of the mathematical creativity task. Before analyzing our research question, we had to score the mathematical creativity measure. We first coded the answers of the creativity tasks into the three aspects of fluency, originality, and flexibility. For the fluency aspect, we simply counted all correct given answers to obtain one fluency score per person per task. When it comes to the originality aspect, only answers from different categories were counted, which means that students giving answers on different categories received a higher originality score than students providing a lot of relevant answers, but all of them came from a single category. The different categories included here were, for example, "Polygon acquires shape of a circle, rounded", "Radius changes", "Center point appears", or "Drawing altitude to triangle or figure increases, doubles number of shapes, triangles" (Balka, 1974). For the scoring of the flexibility aspect, three weighting categories were used based on the respective sample. Zero was assigned for every category mentioned by more than 5% of the students. A weight of one was assigned for every category that 5 to 2% of the students mentioned, and the highest weight was assigned for every category mentioned by less than 2% of the students. As such, the flexibility score was based on answers with a weight of one and two, and a sum score of all weighted answers was calculated for each student (see also Supplementary SB for the scoring procedure exemplified by the first task). The standardized score of all three aspects was used to develop a latent mathematical creativity scale measuring the overall performance per task, consisting of an originality, fluency, and flexibility score.

6.4. Data Analyses

Before the final analyses, the self-reported levels of over- and underchallenge and students' grades on their mathematics exam as a more objective ability measure were standardized to convert them to the same metric (e.g., Wen et al., 2010). Students' level of overchallenge was then assessed, combining their perceived level of overchallenge (ranging from no overchallenge to a very strong overchallenge) and their standardized grade score (ranging from a very low to a very high score indicating a decreasing performance, hence increasing overchallenge). Students' underchallenge, on the other hand, was assessed, combining their perceived level of underchallenge (ranging from no underchallenge to very strong underchallenge) and their recorded standardized grade score (ranging from a very high to a very low score, indicating an increasing performance, hence increasing underchallenge)[1].

In terms of the creativity measure, we investigated the internal reliabilities of the three categories, fluency, flexibility, and originality, separated by the three tasks. In a second step, a confirmatory factor analysis was used to investigate if the three tasks measured one construct, mathematical creativity, which would make it possible to merge all three tasks investigating our main hypotheses.

A power analysis was conducted using G*Power (Faul et al., 2009) to evaluate the statistical power and determine the sample size needed for structural equation modeling analysis. A post hoc power analysis was conducted to test the actual effect based on the given study sample (Jobst et al., 2023). The analysis revealed that the likelihood of falsifying the model, even though it is incorrect, is 95.096% with a sample size of 119.

Structural equation modeling (SEM) was conducted in Mplus 8.6 (1998–2017). As a first step, measurement models were constructed, estimating the latent constructs of students' level of overchallenge in mathematics (combined perceived overchallenge and a grade on their last mathematics exam) and students' level of underchallenge in mathematics (combined perceived underchallenge and their recoded grade on the last mathematics exam), together with students' mathematics-related boredom (including all six manifest boredom variables covering the four different components of boredom) and performance on mathematical creativity in task one, two, and three (including the manifest fluency, flexibility, and originality score). Finally, two structural models were estimated via a random slope approach to interaction modeling (Muthén & Asparouhov, 2003) with a full-information maximum likelihood estimation procedure suggested by Klein and Moosbrugger (2000) and by using the MLR-estimator to account for possible non-normality problems (1998–2017). All variables were standardized before entering them into the models, but unstandardized beta weights were reported according to the recommendations of Kline (2011) and Preacher et al. (2006). Model 1 resulted in an estimation of the conditional effects of boredom and level of overchallenge together with the interaction effect of boredom with the level of overchallenge on students' performance on mathematics creativity tasks. Model

2 estimated identical effects by substituting over- with underchallenge. Missing data were handled with full information maximum likelihood procedures (Arbuckle, 1996; Rubin, 1976). Due to the fact that achievement in mathematics in general is a very strong predictor of performance on mathematical creativity tasks (e.g., Bahar & Maker, 2011) and can presumably explain a relevant part of variance, we additionally controlled for students' mathematics grades on their last report card. As we wanted to exclude the possible influences of gender, age, and the rotation of the creativity tasks, these variables were furthermore included into all of our analyses together with a variable accounting for the nested data structure (students within classes).

7. Results

7.1. Preliminary Analyses

Descriptive statistics revealed a mean of M = 1.97 (SD = 1.05) in the case of students' perceived underchallenge and M = 2.03 (SD = 0.88) in the case of perceived overchallenge, with 24.3% of students reporting scores $\geq$ three in the case of being underchallenged and 25.1% in the case of being overchallenged. The average students' grade in the last mathematics exam as an objective challenge measure was M = 2.64 (SD = 0.94). Looking at boredom, 92.4% of students reported a boredom score $\geq$ three (hence, they were at least slightly bored) with 2.5% reporting a score of five (*very strong boredom*) and 19.2% of four (*strong boredom*), with an overall mean of M = 2.60 (SD = 0.92), which means students experienced overall moderate boredom. Internal reliabilities for boredom and the three investigated categories of fluency, flexibility, and originality of the creativity tasks showed acceptable reliabilities (see Tables 1 and 2 for descriptive results, reliability measures, and intercorrelations of key study variables).

Table 1. Reliability measures of boredom and creativity, item discriminations of the three creativity categories fluency, flexibility, and originality, and descriptives of key study variables.

Measure	Cronbach's α	Guttman's λ_2	r_{it} Fluency	r_{it} Flexibility	r_{it} Originality	M	SD
Perceived Overchallenge	-	-	-	-	-	2.03	0.88
Perceived Underchallenge	-	-	-	-	-	1.97	1.05
Grade last Math Exam	-	-	-	-	-	2.64	0.94
Boredom	0.88	0.88	-	-	-	2.60	0.92
Creativity Task 1	0.89	0.84	0.73	0.86	0.73	6.39	4.46
Creativity Task 2	0.75	0.76	0.61	0.75	0.62	4.50	3.28
Creativity Task 3	0.79	0.82	0.76	0.78	0.76	7.66	5.03

Note. M and SD are based on manifest variables (in case of over-, underchallenge, and grade) or sumscores of manifest variables (in case of boredom and the creativity tasks).

Confirmatory factor analysis included all three tasks consisting of the three categories; each showed no satisfactory model fit (RMSEA = 0.09; TLI = 0.94) and (very) low correlations between the tasks ($r_{1\text{with}2}$ = 0.013, $r_{1\text{with}3}$ = 0.082, $r_{2\text{with}3}$ = 0.298). Hence, it was not possible to build one factor, "mathematical creativity", consisting of all three tasks. However, RMSEA values are determined by Chi-square statistics, and it is crucial to recognize that any violations of multivariate normality will impact the inflation of this index. Besides, smaller models may have more constraints in degrees of freedom, which makes RMSEA more sensitive to model size (Breivik & Olsson, 2001). The weak correlations between tasks lead us to consider each mathematical creativity task individually. As a result, we investigated the postulated effects in our main analyses separately for the three mathematical creativity tasks and applied measurement models for all three tasks, including the standardized fluency, flexibility, and originality scores of the three tasks.

Table 2. Intercorrelations of key study variables.

Measure	1	2	3	4	5	6	7	8	9	10	11
1. OC	-										
2. UC	−0.31 **	-									
3. GRADE	0.38 **	−0.31 **	-								
4. BO_1	0.16	−0.15	0.15	-							
5. BO_2	0.25 **	−0.24 *	0.33 **	0.42 **	-						
6. BO_3	0.26 **	−0.15	0.23 *	0.54 **	0.59 **	-					
7. BO_4	0.30 **	−0.24* *	0.25 **	0.58 **	0.57 **	0.74 **	-				
8. BO_5	0.23 *	−0.15	0.16	0.34 **	0.47 **	0.59 **	0.68 **	-			
9. BO_6	0.38 **	−0.11	0.28 **	0.32 **	0.49 **	0.62 **	0.59 **	0.48 **	-		
10. CREA_1	−0.06	0.17	−0.38 **	−0.02	−0.13	−0.13	−0.09	−0.09	−0.17	-	
11. CREA_2	−0.13	0.04	−0.23 *	−0.06	−0.08	−0.08	−0.11	−0.01	−0.12	0.12	-
12. CREA_3	−0.06	−0.03	−0.13	−0.09	−0.07	−0.08	−0.08	−0.13	−0.05	0.07	0.28 **

Note. OC = perceived overchallenge; UC = perceived underchallenge; GRADE = students' grade on their last mathematics exam bounded by 1 (highest possible grade) to 6 (lowest possible grade); BO = Boredom; CREA = Creativity; reported coefficients are product-moment correlations based on manifest variables. * $p < 0.05$; ** $p < 0.01$.

7.2. Main Analyses

Model 1 (for a graphical illustration see Figure 1) investigates the influence of students' boredom, level of overchallenge, and potential interactions of student boredom with the level of overchallenge revealed not being significant (conditional) and affecting neither boredom (b_{BO} = 1.66, p = 0.100) nor students' level of overchallenge (b_{OC} = -0.23, p = 0.720) on mathematical creativity measured by task one. The latent interaction of students' boredom experiences with their level of overchallenge revealed a significant interaction effect on mathematical creativity in task one ($b_{BO \times OC} = -0.40$, $p < 0.05$). As such, the strength of the effect of boredom varied depending on students' level of overchallenge. More precisely, the slope of the regression of mathematical creativity predicted by boredom was reduced by 0.40 when students' overchallenge increased by one unit. Model 2 (for a graphical illustration see Figure 2) revealed an identical result pattern when looking at the conditional effects, with non-significant conditional effects in case of boredom (b_{BO} = 1.60, p = 0.113) and students' level of underchallenge (b_{UC} = 0.25, p = 0.679) on mathematical creativity measured by task one. In the case of the latent interaction of students' boredom experiences with their level of underchallenge, we again showed a significant interaction effect ($b_{BO \times UC}$ = 0.38, $p < 0.05$). As such, the strength of the effect of boredom varied depending on students' level of underchallenge. The interaction effect was positive (whereas in the case of overchallenge, a negative interaction effect occurred), and the slope of the mathematical creativity predicted by boredom was increased by 0.38 with an increasing level of underchallenge. When looking at the same analyses for the creativity tasks two and three, we could not find any significant results. This also holds true when combining tasks two and three (which showed stronger intercorrelations), constructing a higher order model[2].

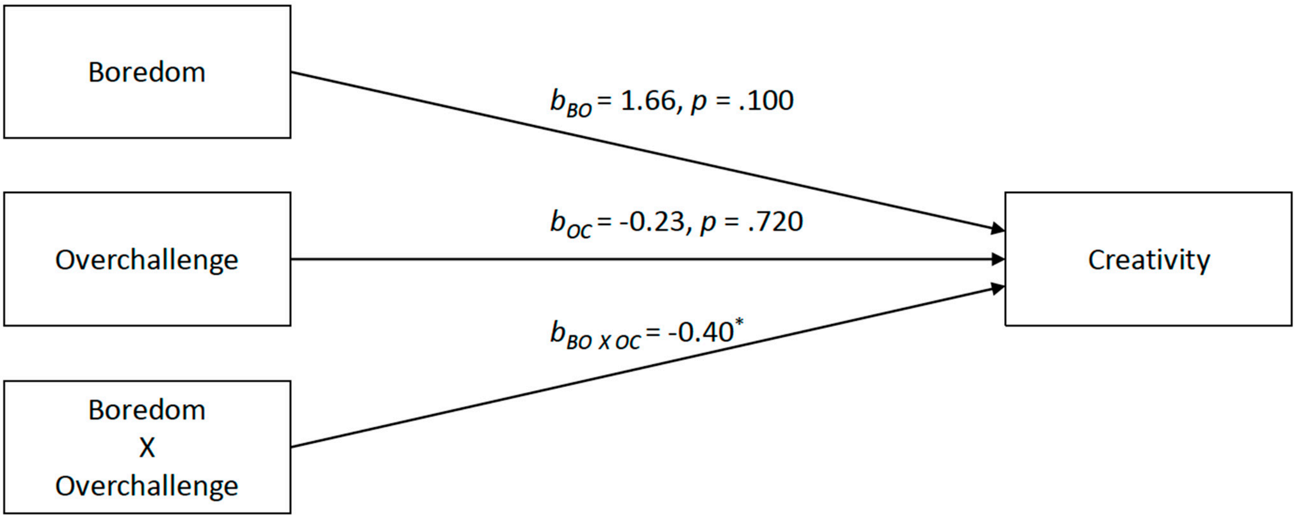

Figure 1. Graphical depiction of model 1. Unstandardized regression coefficients (*b*). *OC* = Overchallenge; *BO* = Boredom. * $p < 0.05$.

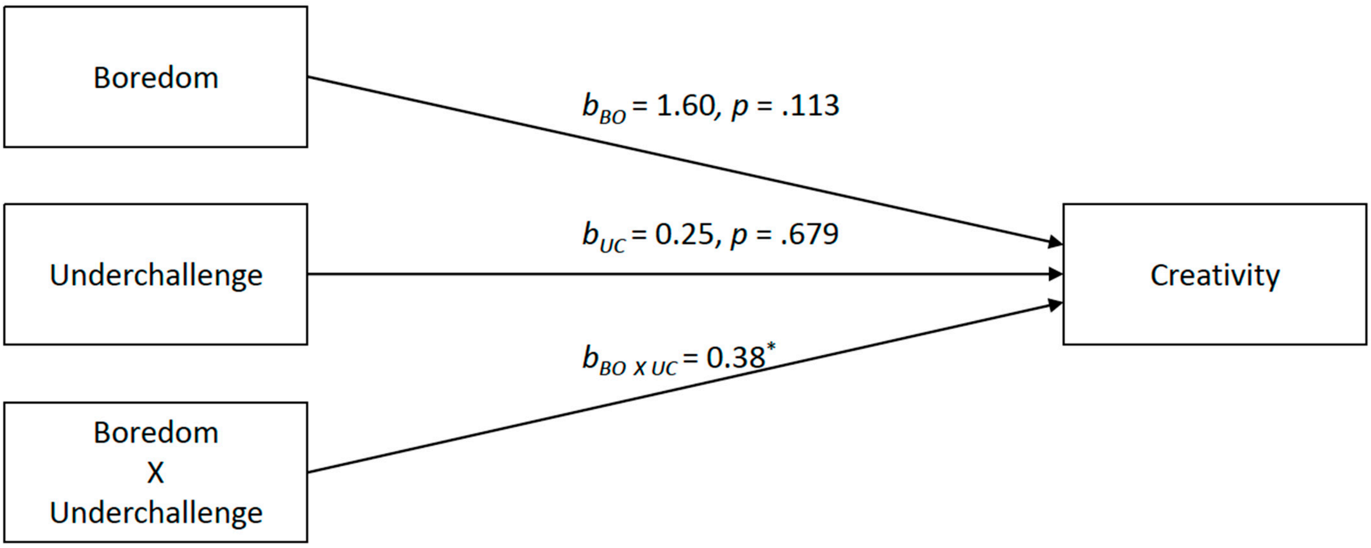

Figure 2. Graphical depiction of model 2. Unstandardized regression coefficients (*b*). *UC* = Overchallenge; *BO* = Boredom. * $p < 0.05$.

8. Discussion

In this study, we investigated the effects of boredom and students being over- or underchallenged, separately and in interaction, on student performance on mathematics creativity tasks. By doing so, we were especially interested in the combined effects of students' boredom with either over- or underchallenge postulating differential effects on creative performance that have not been previously explored. Consistent with our hypothesis, the interaction effect of boredom combined with overchallenge was the opposite of the interaction effect of boredom combined with underchallenge in the first creativity task. Whereas higher levels of boredom with higher levels of overchallenge significantly decreased students' mathematical creativity (as compared to boredom in combination with lower overchallenge), higher boredom with higher underchallenge (as compared to lower underchallenge) enhanced it (Becker & Shimada, 1997; Kaufman, 2009; Livne, 1999; Pehkonen, 1997).

As such, boredom in combination with overchallenge seems to function differently from boredom combined with underchallenge when it comes to creativity, which is a very important finding, especially in light of the mixed theoretical and empirical considerations with regard to the boredom–creativity link. This finding indicates differential attentional mechanisms connected to boredom with either over- or understimulation. Generally, boredom provides the basis for either an attentional drift off to irrelevant thoughts or a broadened attentional focus to thoughts, which are considered as "irrelevant" for very closed tasks but helpful for unconventional creative thinking (Kasof, 1997). This state of mind occurs when students are underchallenged, hence freeing up their cognitive resources, and boredom enables a new combination of thoughts and a broadened way of thinking. Conversely, boredom with high overchallenge does not have positive effects on performance on creativity tasks due to lacking resources for original and effective thoughts. Hence, when bored and overchallenged, students may engage in task-irrelevant things (e.g., what they could do after school; Kahneman, 1973), showing a clear preference for undemanding thoughts perceived as effortless (Job et al., 2010; Krannich & Goetz, 2021; Westgate & Wilson, 2018). In this case, boredom may function as a deactivating (e.g., Acee et al., 2010; Gasper & Middlewood, 2014; Sharp et al., 2018) avoidance-oriented emotion (e.g., Nett et al., 2010; Pekrun et al., 2010). This is in line with results from Nett et al. (2019) that showed a negative link of boredom with cognitive-avoidance coping strategies under the overchallenged condition but not in the case of boredom when being underchallenged.

Supporting the assumptions by the MAC model from a cognitive load perspective, our findings suggest that bored people need working memory capacity to produce novel and effective thoughts when already schematized information from long-term memory is no longer sufficient for problem-solving (Sweller, 2009; Sweller & Sweller, 2006). As such, overchallenged students are simply not able to invest more resources into producing creative answers to the mathematical creativity tasks. This is also consistent with the results of a recent study by Goetz et al. (2023), who examined the relations of boredom during math tests with performance on these tests. They found that boredom was negatively related to test scores in the difficult part of the test (i.e., when being overchallenged) but unrelated to test scores in the easy part of the test (i.e., when being underchallenged). In combination with boredom, a disengagement from the situation may occur, hindering fluent information processing (Winkielman et al., 2002) together with attentional disinvolvement (Eastwood et al., 2012) from the creativity tasks (Nakamura & Csikszentmihalyi, 2002), resulting in a decrease in creativity. On the other hand, underchallenged students do possess this capacity and may experience information-processing fluency (Winkielman et al., 2002), but these cognitive resources alone are not sufficient to enhance creative thinking, as only in combination with boredom students find themselves in an attentional state actively searching for engagement (Hamilton et al., 1984). This state is resolved by students' attempts to find cognitive stimulation through novel thoughts (Gasper & Middlewood, 2014), whereas overchallenged students fail to invest capacities into the creativity tasks due to depleted cognitive resources. It is therefore safe to suggest that "overchallenged and underchallenged boredom" may be considered a useful dichotomy of boredom with different cognitive and attentional consequences for various meaningful outcomes (Berlyne, 1960; Goetz et al., 2014; Krannich et al., 2022; Krannich & Goetz, 2021; Merrifield & Danckert, 2014; Mikulas & Vodanovich, 1993; Westgate & Wilson, 2018)[3].

However, we did not find interaction effects in tasks two and three. Nevertheless, task one was the most reliable of the three tasks with a Cronbach's alpha of 0.89 and a Guttman's lambda of 0.84, and tasks two and three showed lower internal consistencies compared to task one (Cronbach, 1951; Guttman, 1945). Hence, it is reasonable to assume that tasks two and three did not measure creativity with its underlying aspects of fluency, flexibility, and originality very well, which might explain the insignificant findings. One additional potential explanation for the non-significant findings might be that the students simply did not understand these tasks well as they did task one, as task one was the only one with a pictorial representation. Furthermore, both tasks two and three are even more openly phrased in comparison to task one. Although creativity tasks are meant to be constructed as open-ended tasks allowing the problem-solver to give flexible and open answers (Becker & Shimada, 1997; Mann, 2005; Pehkonen, 1997), it is important that students comprehend the concept behind these tasks enabling them to produce novel but also effective thoughts (e.g., Barron, 1955; Stein, 1953; Runco & Jaeger, 2012). This might only have been the case for task one. In retrospect, we had the impression that students appeared to have asked the study supervisors more often about task two and three, compared to task one. However, this assumption is only based on memory, as no quantitative or qualitative data are available.

In addition to the reported interaction, we found that students' challenges had no effect on their performance on all three creativity tasks (under the assumption of boredom being zero). As such, students' mathematical creativity was not impacted by their level of challenge—neither in the case of under- or in that of overchallenge. The same pattern was true for boredom controlling for students' level of challenge in both directions. This non-significant pattern of results across the three tasks does not contradict considerations that postulate positive consequences of boredom (Brissett & Snow, 1993; Toohey, 2011; Vodanovich, 2003) or those that classify boredom as aversive (e.g., Goetz et al., 2019, 2024; Fisher, 1993; Mikulas & Vodanovich, 1993; Pekrun et al., 2010). The interaction effects occurring in task one indicate the need for a differentiated look at the boredom–creativity link that includes students' challenges.

9. Strengths of the Study, Limitations, and Implications

Our study assessed student boredom, challenge, and mathematical creativity during mathematics classes in a sample of eighth graders from six different classes. As such, the proposed relations were investigated in a natural school environment in typical school situations. We examined the combined effects of two naturally emerging groups, namely students who were bored and overchallenged in mathematics classes and students who were bored and underchallenged in mathematics classes, on three different mathematical creativity tasks. By doing so, the results of our study are highly ecologically valid (e.g., Mehl & Conner, 2012). However, using self-reported measures may be a limitation when assessing boredom. Self-report measures can introduce common-method bias in behavioral research, indicating variance due to the measurement methods rather than the studied constructs (Podsakoff et al., 2003). In this regard, social desirability acts as a potential source of common-method bias. Participants may conceal their true ideas and feelings on a given topic to gain acceptance or approval from researchers, which can jeopardize internal validity. Additionally, self-report measures in this study are influenced by students' retrospective thinking, which also seems a limitation when assessing emotions due to including memory biases and not capturing the momentary expressions of students. Moreover, the behavioral and physiological aspects of emotions, particularly boredom, may not be adequately captured through self-report measures (Pekrun, 2024). Therefore, further research might incorporate using multiple assessments, including mental and physiological indicators (Pekrun, 2023). As the results of the study are ecologically valid, the significant result for task one can be considered very encouraging. The study introduces the nuanced idea that both boredom and overchallenge can hinder creativity, suggesting that an optimal level of challenge is necessary for fostering creativity. This perspective challenges traditional educational assumptions such as viewing underchallenge as a space where exploration can thrive rather than as a negative factor. That underscores the importance of balancing challenges in the classroom. Furthermore, on a methodological level, two arguments underline the promising effect of task one. First, the detection of interaction effects, especially in natural non-experimental settings, is extremely difficult (Guo et al., 2016), and these effects are considered as being generally small (Nagengast et al., 2011). Second, caused by the ecologically strong research design, we did not experimentally manipulate the selection of students to the group of over- or underchallenge resulting in a non-normal distribution of these variables, which, again, might have hampered the detection of possible interactions. Thus, school studies with a bigger sample size and a quasi-experimental manipulation of over- and underchallenge are needed to corroborate the findings of this study. In addition, future studies should assess students' actual over- and underchallenge in an even more objective way. We indexed students' levels of over- and underchallenge by combining a perceived measure with a measure of students' grades in their last exam. Investigation of the boredom–creativity link may benefit from an actual testing of students' momentary over- or underchallenge via standardized competence tests assessing individuals' ability along with item difficulties (e.g., Embretson & Reise, 2000; Tymms, 2010). Furthermore, looking at different types of mathematical creativity tasks might be promising to examine a potential differential impact by students' boredom and challenge as suggested by our study. Following this promising avenue of research, these studies could additionally make an important contribution to our understanding of the underlying (cognitive) mechanisms leading to the complex result pattern of the boredom–creativity link.

Our results suggest that high levels of boredom at school should be prevented when occurring in combination with high levels of overchallenge. The significant negative interaction effect of boredom and overchallenge on creativity in the first task underlines the potential detrimental effects of this emotion at school arising from non-optimal fit in the direction of being overchallenged (Krannich et al., 2019, 2022; Sparfeldt et al., 2011). This combination might inhibit the rise of creative mathematical thoughts and, therefore, in the long run, potentially prevent the development of innovative mathematical ideas (Elsbach & Hargadon, 2006). When looking at the combined effect of boredom and underchallenge and considering the results of the first task, one could cautiously speculate that boredom together with higher levels of underchallenge may enhance mathematical creative thinking in special cases as the effect of underchallenge alone was non-significant and therefore not sufficient to enhance mathematical creativity (Plucker & Renzulli, 1999; Sweller et al., 1998). Nevertheless, future studies to further explore this assumption are needed. In this context, the inclusion of students' enjoyment seems to be a highly promising avenue of research. Studies could examine whether a combination of underchallenge and enjoyment might further enhance performance on mathematical creativity tasks, lowering the attentional difficulties arising from boredom (Danckert & Merrifield, 2016; Eastwood et al., 2012; Westgate & Wilson, 2018). From a practical point of view—and based on the interaction effects—we can conclude that boredom at school should be avoided. In general, preventing overchallenge may be difficult to accomplish. First, teachers have to deal with a heterogeneous student body, which makes the notion of optimal challenge at all times almost impossible. Second, if overchallenge occurs, this would call for a correct estimation of students' level of boredom to avoid negative effects on creative thinking. During class, such an in-time and precise estimation of students' boredom is a highly complex task for teachers (e.g., Warwas et al., 2015). Studies have already shown that teachers' diagnostic competencies are error-prone, especially in case of affective variables (e.g., Südkamp et al., 2012; Urhahne et al., 2010). Therefore, a complete elimination of boredom in combination with overchallenge is difficult to accomplish. However, the study emphasizes the need for teachers to recognize their students' emotions, particularly boredom. Future research might examine the effectiveness of professional development programs in improving teachers' diagnostic skills to identify students' emotions. Moreover, studies may also explore how teachers' perceptions of students' boredom affect their instructional practices and overall classroom environment.

Our study results were also restricted to German school settings, particularly from the Gymnasium track. The German education system follows a three-tier tracking system that includes three different types of schools based on students' ages. In the first track, students in grades 1 to 4 attend a four-year primary school. After completing primary school, students progress to one of three secondary schools: Hauptschule, Realschule, or Gymnasium. A Gymnasium is the highest track within the German secondary school system, preparing students for higher education (e.g., Schneider & Tieben, 2011). Schwartze et al. (2024) found that students experience boredom when they are either over-challenged or underchallenged in mathematics. Interestingly, students in the upper-school track were less represented among those who felt underchallenged, likely because the more demanding curriculum in this track helps to prevent such situations. Therefore, our findings can only be considered and generalized to the upper-school track, given that our study sample is drawn exclusively from the Gymnasium. This limitation affects the ecological generalizability of the results, which could potentially be addressed by including a broader range of educational systems. This would provide a more comprehensive understanding of how boredom and challenge impact creativity across different educational contexts.

In summary, the current research sheds light on the interaction between students' level of challenge and their boredom during mathematics class, investigating its impact on mathematical creativity tasks. By doing so, this study further supports cognition–emotion interactions for learning and creative behavior (Dalgleish & Power, 1999; Ledoux, 1989; Meyer & Turner, 2006; Pekrun & Linnenbrink-Garcia, 2012) and stresses the need for a more detailed investigation of students' boredom in combination with either being over- versus underchallenged to better understand the underlying attentional and motivational consequences of this widespread academic emotion (Goetz & Hall, 2014; Goetz et al., 2024; Pekrun & Goetz, 2024). Lastly, longitudinal research that examines the impact of boredom and challenge on creativity over time could provide insights into how these emotional states and challenges affect students' creativity and academic outcomes in the long run. It is our hope that in the future, this line of research will further enable students to optimally deal with boredom and utilize it to foster students' creativity and a broadened way of thinking and support learners to develop their potentials (e.g., Baas et al., 2008; Burnard, 2006).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci15030330/s1, Supplementary SA: Used Instrument Assessing Mathematical Creativity via Three Tasks; Supplementary SB: Scoring Procedure and Weights of the Flexibility Score Exemplified by the First Task Assessing Mathematical Creativity.

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Notes

1 As described earlier, we assumed that students' perceived measures of over- and underchallenge can be biased. Descriptive data has shown, for example, that over 25% of students having scores of overchallenge > 1 (at least some overchallenge) and grades on their last mathematics exam of 1 (excellent) or 2 (good). Hence, we combined the perceived measures of challenge with a more objective one—students' grade on their last mathematics exam—to enhance the validity of the construct of over- or underchallenge, respectively (Messick, 1980). However, this resulted in two measures, which, to some degree, relied on different underlying constructs and did not meet the condition of essential tau-equivalence as a precondition of reliability measures, such as Cronbach's alpha (Graham, 2006; Raykov, 2001; Trizano-Hermosilla & Alvarado, 2016). We therefore tested the measurement model estimating a latent factor "level of overchallenge" by the two variables of perceived overchallenge and grade. This model revealed a highly significant factor loading of $\lambda_{Ov} = 0.68$ *** (when fixing the loading of grade to 1), justifying the combination of the two variables to build a construct "level of overchallenge". Testing the measurement model estimating a latent factor "level of underchallenge" by the two variables, perceived underchallenge and grade, the model revealed a factor loading of $\lambda_{Un} = 0.35$ * (when fixing the loading of grade to 1). Thus, the factor loading of perceived underchallenge was satisfactory. Hence, the combination of perceived underchallenge and the recoded grade was also legitimatized.

2 We furthermore estimated an additional model including a Dummy-variable of challenge with an assigned value of zero when the perceived underchallenge was >1 and grade was <3 and an assigned value of one when the perceived overchallenge was > and grade was >3. For the creativity task one, this model resulted in non-significant conditional effects of boredom ($b_{BO} = 0.49$, $p = 0.114$) and challenge (as a Dummy-variable; $b_{Challenge} = -0.35$, $p = 0.862$). We again showed a significant interaction effect of boredom x challenge ($b_{BO \times Challenge} = -0.85$, $p > 0.05$), indicating lower creativity when students' level of boredom increases in combination with overchallenge (and higher creativity in the case of higher boredom in combination with underchallenge). Thus, this result in the case of a Dummy-coding procedure additionally supported our hypotheses.

3 These attentional failures (e.g., Carriere et al., 2008) are, for example, plausibly strongly connected to students' arousal (Eastwood et al., 2012; Freeman et al., 2004). In case of cognitive demands exceeding mental resources (i.e., arising overchallenge), arousal might be higher than in the case of cognitive demands falling behind the available mental resources (i.e., arising underchallenge; e.g., Freeman et al., 2004; Pekrun et al., 2010), while in both cases boredom occurs (Fahlman et al., 2013; Daschmann et al., 2011; Pekrun et al., 2010). With that said, ongoing debate when it comes to the arousal dimension of boredom (Danckert et al., 2018; Eastwood et al., 2012) with researchers associating boredom with high arousal (e.g., Jang et al., 2015; London et al., 1972; Merrifield & Danckert, 2014), whereas others characterize boredom as a state of low arousal (e.g., Mikulas & Vodanovich, 1993; Pattyn et al., 2008; Russell, 1980) that might additionally benefit from the postulated differentiation of boredom.

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