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Priming creativity: Doing math reduces creativity and happiness whereas playing short online games enhance them

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Creative thinking is an indispensable cognitive skill that is becoming increasingly important. In the present research, we tested the impact of games on creativity and emotions in a between-subject online experiment with four conditions (N = 658). (1) participants played a simple puzzle game that allowed many solutions (priming divergent thinking); (2) participants played a short game that required one fitting solution (priming convergent thinking); (3) participants performed mental arithmetic; (4) passive control condition. Results show that divergent and convergent creativity were higher after playing games and lower after mental arithmetic. Positive emotions did not function as a mediator, even though they were also heightened after playing the games and lower after mental arithmetic. However, contrary to previous research, we found no direct effect of emotions, creative self-efficacy, and growth- vs. fixed on creative performance. We discuss practical implications for digital learning and application settings.

KEYWORDS

creativity, priming, enhancement, math, games, happiness

Introduction

Digital learning scenarios are becoming increasingly important, as they increase access to education and knowledge acquisition worldwide (Sailer et al., 2021). Especially the response measures to reduce the spread of the COVID-19 pandemic caused a shift toward online teaching (Chiu et al., 2021). One often-used component are gamified learning elements or games. Gaming supports learning processes, as learning progress is usually more visible with games than with traditional learning methods. Additionally, the gameplay is often perceived as rewarding, as the playfulness elicits positive emotions (Li et al., 2022). Positive game-based learning effects could be demonstrated from diverse research angles: education research (Plass et al., 2015), psychology (Pavlas et al., 2010), neuroscience (Howard-Jones and Jay, 2016), and organizational studies (Hernández and Moreno, 2018). Digital game-based learning positively influences the learner's affection (e.g., enjoyment), cognition (e.g., cognitive load), and behavior (e.g., intention to participate in learning; Koivisto and Hamari, 2019). On the downside, learning with games potentially lacks ecological validity, especially as games tend to be oversimplistic (Li et al., 2022). Consequently, the benefits of digital games could be harvested by using them to increase motivation rather than to teach students specific learning content. This gamification approach is often used to improve the engagement of the participants in online courses (Subhash and Cudney, 2018).

Due to the emotional engagement and playful character, gamified learning contexts are believed to be associated with creativity (Agogué et al., 2015). Creativity is an essential individual skill that becomes more important in an increasingly complex, digitalized world (van Laar et al., 2017). When creativity is nurtured, this can have benefits for the individual, as well as for the society as a whole (Glăveanu, 2018). Games can support individual creative thinking skills in many ways. Here we focus on two: First, games can directly impact creativity by acting as a prime (Haase, 2020), thereby making specific patterns of thinking more likely to occur. Second, engaging in games can activate positive emotions, which are positively associated with creativity (Baas et al., 2008).

Even though gamified learning contexts, as well as teaching and training methods to enhance creativity, are both intensely researched areas, the impact of games on creative performance in digital learning settings is not well studied and theorized yet. Usually, the educational impact of complex games that are played for several hours is studied (e.g., Ashinoff, 2014; Halbrook et al., 2019). As gamified learning contexts with only short game-like aspects are increasingly used in learning scenarios, their impact on creative thinking needs to be better understood. This study aims to elicit more information on the relation between short gameplay and subsequent creative performance by setting up an experiment to test this impact with different games.

Enhancing creativity

Creativity is a complex individual trait characterized by cognitive elements, personality traits, and social embeddedness (Glăveanu et al., 2019). Therefore, there are a diverse set of methods to enhance creativity (Scott et al., 2004b), such as more complex and time-consuming training sessions (Birdi, 2005), short-term interventions like meditation (Colzato et al., 2012), physical movement (Campion and Levita, 2014), and cultural exposure (Maddux et al., 2010). Overall, those enhancement methods can be distinguished into conscious training methods vs. unconscious stimulation. Whereas training helps to understand the creative process better and potentially improves the creative self-perception through positive feedback on creative performances (Scott et al., 2004a), short-term stimulations influence the individual situational mindset (DeCoster and Claypool, 2004) and impact emotions which are also related to creative performances (Newton, 2013).

Emotions

Emotions can enhance creative task motivation. Research repeatedly showed that associations flow best when the person is in an active, positive emotional state (Amabile et al., 2005; Baas et al., 2008). Negative emotions such as emotional pain and frustration can also lead to more creativity, but mainly only after an extended period: Negative emotions lower initial task motivation but can increase the search for creative solutions to counter the cause of frustration or pain (Newton, 2013). However, as it is ethically problematic to induce negative emotions in a learning setting, our research focuses on positive, especially engaging emotions to foster creative performance. There is also a circular relation between positive situational emotions and individual self-evaluation. Students in a more positive mood rate their creative self-efficacy higher, engage more in learning opportunities, and tend to report a greater increase in their creative self-efficacy through the learning experience (Tan et al., 2008).

Interventions, such as playing games that lead to heightened emotions, were found also to increase the creative performance (for a tabletop role-playing game, see Dyson et al., 2016). Games were repeatedly found to improve players' positive and negative emotions, depending on the game content (Ninaus et al., 2019; Cheng et al., 2020). Gamifying learning content leads to greater engagement with the content and a more positive learning experience (Zatarain Cabada et al., 2020). This association qualifies game content in a digital learning setting to show positive effects on creative performances by increasing the task motivation through emotions.

Creative mindset

A positive, creative self-concept is essential to be creativity (Karwowski and Brzeski, 2017). A creative mindset is an enduring belief about one's creative abilities and situational cognitive conditioning. For the former, individuals who believe in their creative competencies are more likely to face creative challenges and persist through difficulties (Beeftink et al., 2012). This individual's *creative self-efficacy* (CSE), defined as the belief in one self's creative abilities (Tierney and Farmer, 2002), can be enhanced through positive feedback on actual performance. Creative self-efficacy is positively associated with creativity (Haase et al., 2018). When the task is slightly demanding, a positive accomplishment will enhance individual beliefs about mastering them (Byrge and Tang, 2015). Personal feedback on task performance and individualized learning content are strengths of digital learning scenarios (Jensen et al., 2021).

For the creative mindset as a situational cognitive conditioning, the mental operations allow for flexible, broad, and remote associations (Sassenberg et al., 2022). Such mental processing is based on global perception and increased working memory capacity (Dreu et al., 2010). This "should facilitate the processing of remote rather than close associations, and thus increase cognitive flexibility" (Sassenberg et al., 2017, p. 129), which is the basis for creative thoughts. Such a mindset cannot be achieved by willpower alone, but priming methods can induce it (Sassenberg and Moskowitz, 2005; Sassenberg et al., 2017).

Priming a creative mindset

Priming is "the presentation of a stimulus designed to subconsciously implant a concept in working memory that alters subsequent behavior" (Dennis et al., 2013, p. 195). When individuals are presented with certain information, the associated mental representation evokes equivalent changes in the individual's behavior. Various concepts can be primed, including counterfactual thinking (Galinsky et al., 2000), stereotype-activation (Sassenberg and Moskowitz, 2005), deliberative vs. implemental thinking (Gollwitzer et al., 1990), individualistic vs. collectivistic norms (Bechtoldt et al., 2012), or achievement (Dennis et al., 2013). They all result in a mindset activation, an adjusted thinking pattern, and, finally, better preparedness for subsequent tasks (Gollwitzer et al., 1990). By priming a mindset, people tend to behave or think in line with the primed mindset even in an unrelated context (Sassenberg et al., 2007).

The central issue with creative thinking is that it cannot be forced (Sadler-Smith, 2015). When individuals are asked to be more creative, they cannot intentionally activate a broad, free-flowing associative thinking network. This makes the priming paradigm so promising for improving creative work, as it aims to alter subconscious thinking processes without the person's awareness (Sassenberg and Moskowitz, 2005). Studies that primed creativity achieved this by presenting stimuli without participants' awareness of its priming intention (Dennis et al., 2013). Directly priming remote associations is an effective way to improve a person's immediate creative performance. In several experiments, participants were instructed to remember past creative experiences, which increased their mindset of remote associations, leading to better creative performance. Such positive priming effects were still found when participants' emotions were controlled for (Sassenberg et al., 2017).

A creative mindset can also be indirectly primed. For example, adjusting light conditions in the workplace, with darker settings, leads to better creative performance (Steidle and Werth, 2013). A certain level of darkness potentially evokes the feeling of being free from constraints, facilitating an open, explorative cognitive processing style. In another experimental setting, participants were successfully primed with a creative mindset when exposed to an illuminated lightbulb. Participants were shown the typical image of an *idea* in the form of an enlightened lightbulb before or while they tried to solve an insight problem. This alone led them to solve more insight problems in less time than participants without such a prime (Slepian et al., 2010). These examples show that no complex intervention is required to prime creativity.

Differentiating types of creative thinking

Creative problems can be solved with two distinct types of thinking: associative or divergent thinking vs. convergent thinking. Divergent thinking is based on broad associations which lead to a higher number of possible solutions to an open-ended problem. This thinking style is mainly associated with creativity, as it helps solve problems by bringing in new aspects and ideas (Runco and Acar, 2012). In contrast, selecting one suitable idea from a pool of ideas is convergent thinking. Thereby one solution to a close-ended problem is reached (Cropley, 2006). Thus, the creative process typically requires divergent thinking for generating novel ideas and convergent thinking for reflecting and evaluating those ideas. Since people tend to prefer and perform differently on those measures (Sternberg, 1999), this suggests that they might need to be enhanced differently.

Indeed, primes can affect divergent and convergent thinking differently. For example, Steidle and Werth (2013), who used the darkness-prime, found only significant positive effects on divergent thinking using a drawing task. In contrast, Slepian et al. (2010) found that the lightbulb-prime only affected convergent thinking. Kray et al. (2006) replicated the findings from Slepian et al. (2010) using the same lightbulb prime but surprisingly found reduced divergent thinking scores. In contrast, Sassenberg et al. (2017) found that one prime (thinking of past creative achievements) enhanced divergent and convergent thinking alike, potentially because they activated a holistic creative mindset.

Together, this shows that primes can affect creativity, but it remains unclear how and why primes impact divergent and convergent thinking. In the present experiment, we aim to separately prime both thinking styles.

Gaming to enhance creativity

Games can be used to teach skills, as they transfer knowledge and allow gamers to practice (Chung, 2013; Stolaki and Economides, 2018). Especially engaging and fun games keep players motivated to continue playing and can positively impact creativity.

In a virtual reality scenario, students who break walls and thereby proverbially overcome obstacles to reach a goal scored better in a divergent thinking test compared to a control group (Wang et al., 2018). Participants who were virtually breaking walls also reported greater emotional engagement. They perceived the VR interaction as fun and engaging, which might explain the improved creative performances compared to the control group that did not experience much fun. The positive impact of gaming on creativity was even found for kindergarten children when playing age-appropriate games that stimulate imagination and problem-solving (Behnamnia et al., 2020).

In another student study (Blanco-Herrera et al., 2019), *Minecraft* was used as an example of a game suitable to elicit players' creativity, as it is based on only a few rules and allows players to engage in a virtual world openly. The authors compared *Minecraft* with tv-watching and a car racing game. The racing game players showed the lowest fluency levels (i.e., fewest new ideas) in a divergent thinking measure compared to the other experimental conditions. The explanation by the authors was that some games can enhance functional fixedness, which in turn leads to decreased creative test performance. In contrast, *Minecraft* players outperformed the other conditions on the creativity assessments for divergent thinking and an alien drawing task (used as a performance measure for spontaneous imagination). They further found that participants in an undirected *Minecraft* condition (no instructions on how to play) were more creative, especially in the alien drawing task, compared to a directed *Minecraft* condition (with instructions on how to play). This shows that not only the game scenario creates a difference in creativity but also the degree of freedom the player perceives when engaging with the same game (Blanco-Herrera et al., 2019).

Further, there is some vagueness regarding what kind of game primes the divergent or convergent thinking aspect of creativity. For example, Haase (2020) used short, interactive games to prime a divergent and a convergent thinking mindset, by using a more open vs. closed game. Surprisingly, both games resulted in lower levels of divergent and convergent thinking, even after controlling for emotions. However, the control group did not engage in any demanding cognitive activity. It might therefore be possible that playing the game leads to cognitive fatigue, negatively influencing the subsequent creative task performance (Lorist et al., 2000; Massar et al., 2018).

The studies shortly discussed here demonstrate that games can be used as a prime for a creative mindset, especially when games are fun and allow for flexibility. However, the results are partly inconclusive or contradicting, suggesting that more research is needed to better understand what games influence which type of creative thinking (divergent or convergent).

Research question

The main aim of our experiment is better to understand the impact of short gameplay on creativity. Based on the discussed literature, we postulate that overall engaging, flexible games positively impact divergent and convergent thinking. Therefore, we state the following hypotheses:

> Hypothesis 1. Participants playing an open-end game show higher divergent thinking-test performances compared to the other experimental conditions.

> Hypothesis 2. Participants playing a closed-game show higher convergent thinking-test performances compared to the other experimental conditions.

To consider the potential cognitive fatiguing effects of the gameplay (cf. Haase, 2020), we include additionally to a passive control condition a mental arithmetic (math) condition. The latter task should elicit a focused mindset but might potentially also tire participants out as it requires focus.

> Hypothesis 3. Participants doing mental arithmetic task will show lower creative test performances, compared to the control condition.

Creative performance is not just influenced by a situational mindset, but also by stable self-perceptions of self-efficacy and a fixed-vs. growth mindset (Tierney and Farmer, 2002; Karwowski and Brzeski, 2017; Haase et al., 2018). We therefore postulate:

> Hypothesis 4. A person's creative mindset (CSE and fixed-vs.-growth mindset) moderates the effect of the experimental interventions on divergent and convergent thinking.

As short games are often fun inducing whereas mental arithmetic is less so (Haase et al., 2019), we postulate:

> Hypothesis 5. Participants in both game conditions report more positive emotions than participants in the mental arithmetic condition.

As positive and active emotions are positively associated with creativity (Baas et al., 2008), they influence creative performance.

> Hypothesis 6: Positive and active emotions mediate the priming effect of games on creative performance.

Materials and Methods

Participants

A power analysis with G*Power 3.1.9.4 (Faul et al., 2009) revealed that to detect a small-to-medium effect size of $f = 0.175$

with a power of 0.95 in a one-way factorial design with four levels, a sample size of at least 568 was required. In total, we recruited 658 study participants online on Prolific. However, 20 participants revoked their consent and were excluded. The final sample size consisted of 638 participants (M_{age} = 35.15, SD = 9.48; 328 men, 220 women). Ninety participants reported playing video games between 0 and 3 hours during an average week, 98 between 3–6 h, 98 between 6–9 h, 85 between 10–12 h, and 178 for more than 13 h. About 86 participants were students, whereas 463 were not.

Materials and procedure

We used a one-factorial design with four levels. The study was conducted using a between-subject design. Participants were recruited online via Prolific and paid US-$5.50 for approx. 25 min of their time. The games were integrated into the online survey, which was created in three versions: Participants played a simple digital puzzle game in the first condition that allowed many solutions (divergent thinking condition). In the second condition, participants played a short game that required one fitting solution (convergent thinking condition). In the third condition, participants solved mathematical problems. The fourth condition was a passive control condition. Participants were randomly allocated into one of the four conditions.

Games were administered within the online survey as embedded webpages using HTML. The precise games were chosen based on a small pre-study: six different HTML-based online games were randomly presented to eight participants. They were asked to play the games for around 5 min and report their associations and assumption of the kind of cognition required to play the game. They evaluated one game a day to avoid an impact of previous games on the evaluation of others. Based on the results, a bubble-shooter game (compare **Figure 1**) was chosen for the divergent thinking condition. It was reported to be engaging, fun and allowed for multiple possible actions at a time. A number-sorting game was chosen for the convergent thinking condition (compare **Figure 2**), in which a certain sequence of numbers is found in a square of 9 × 9 numbers. Participants in the mathematical problems condition performed mental arithmetic (e.g., 20 + x = 67; 45-33 = x; 80/x = 4). They were presented with a list of 90 tasks and instructed to solve as many as possible. Participants had three minutes to engage with the game or solve the math tasks for these three conditions.

Next, all participants completed two measures of creative performance: for divergent thinking, a sub-task of the Torrance-Test of Creative Thinking (Torrance, 1972), in which the participants were asked to imagine as many consequences as possible, for the assumption that humans do not need to sleep anymore. Divergent thinking scores of fluency and originality were assessed as measures of quantity and quality of the creative output (Reiter-Palmon et al., 2019). Fluency was counted, and originality was evaluated following the Consensual Assessment Technique (CAT) with two judges, with a high judgment agreement of Cronbach's alpha = 0.95 (Amabile, 1982). Both raters are trained and experienced in rating such divergent thinking scores using the CAT. The Remote Associates Test (RAT) was used for convergent thinking, which measures the convergent thinking (Bowden and Jung-Beeman, 2003). Twenty items were presented for 20 s each. The RAT score was computed as the sum of correct answers.

Participants' state emotions were assessed in the games and math conditions before and after the intervention with three items: happy, active, and excited on a 9-point scale. Test-retest reliabilities were high, r_{it} = 0.71–0.74. We measured creative self-efficacy with three items based on Tierney and Farmer (2002) (α = 0.91). An example item includes "I have confidence in my ability to solve problems creatively." We measured fixed and growth mindsets with ten items of the Creative Mindset Scale (Karwowski, 2014). Example items include "Some people are creative, others aren't – and no practice can change it" (fixed mindset; α = 0.83) and "Anyone can develop his or her creative abilities up to a certain level" (growth mindset; α = 0.80).

Results

Mean comparisons

First, we tested using three one-way ANOVAs whether the three state-emotions *happy, active, and excited groups* differed between groups before the intervention. This was not the case, *ps* = 0.12–0.98. Next, we performed a series of one-way ANOVAs to test whether playing a game or performing mental arithmetic impacts creativity and state emotions. Descriptive and inferential statistics are displayed in **Table 1**. Testing hypothesis 1, the effect of condition on fluency was not significant (see also **Supplementary Figure 1**).

In contrast, the effect of condition on originality was significant, with participants in the convergent condition being, on average more original than participants in the math condition (**Figure 3**).[1] This refutes hypothesis 1, as no positive priming effect could be found for the divergent thinking condition on the divergent thinking measures. In contrast, hypothesis 2 is supported: condition's impact on the RAT (convergent thinking) was significant, with participants in the math and control condition scoring on average significantly

1 For the pairwise comparisons, we set our alpha threshold to0.01 to control for multiple comparisons. We report the uncorrected *p*-values instead of corrected *p*-values because the choice of a method to correct for multiple comparisons (e.g., Holms, Hochberg, Bonferroni) is subjective, and researchers might have different preferences. Since it is more challenging to choose a different correction (e.g., Holm) once a corrected p-value (e.g., Bonferroni) is reported, we report the uncorrected *p*-value.

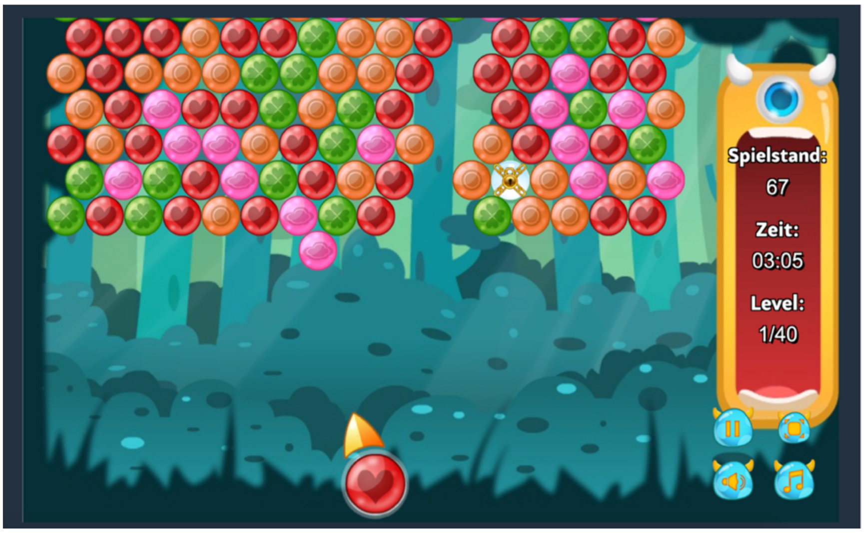

FIGURE 1
Bubble-shooter game used as prime in the divergent thinking condition.

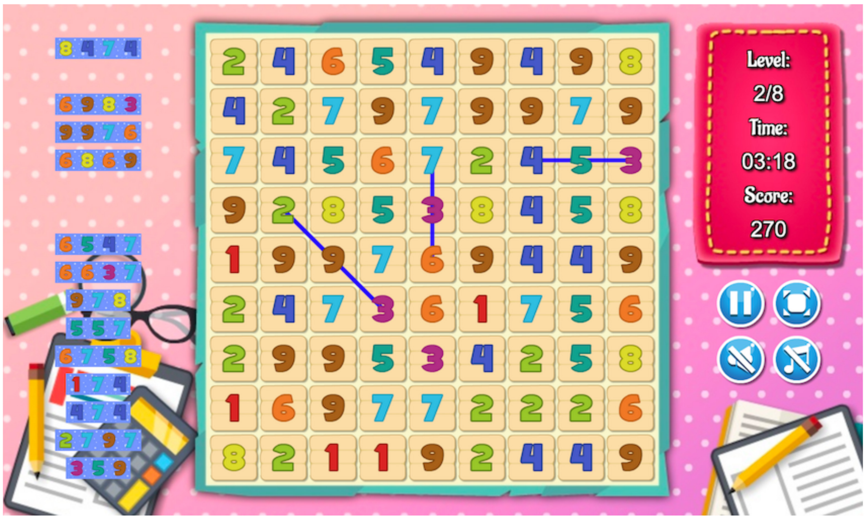

FIGURE 2
Number-sorting game used as prime in the convergent thinking condition.

TABLE 1 Impact of playing games or performing mental arithmetic on creativity and emotions at t2: Descriptive and inferential statistics.

	Control		Convergent		Divergent		Math				
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η_p^2
Fluency	5.57	2.35	5.12	2.46	5.16	2.26	5.53	2.51	1.58	0.194	0.01
Originality	2.52	0.43	2.56	0.43	2.43	0.40	2.39	0.44	5.41	0.001	0.04
RAT	5.28	3.20	7.15	4.09	6.26	3.86	4.54	2.89	15.73	<0.001	0.12
Happy	–	–	6.35	1.68	5.82	1.81	5.02	2.13	17.90	<0.001	0.11
Excited	–	–	5.21	2.17	4.58	2.11	4.43	1.99	5.54	0.004	0.04
Active	–	–	6.65	1.85	6.35	1.84	6.49	2.01	1.01	0.367	0.01

lower than participants in the convergent thinking condition. Additionally, participants in the divergent thinking condition scored on average higher on the RAT than those in the math condition (Figure 4).

Focusing on the math condition, solving arithmetic tasks led to a worse divergent thinking performance in terms of the ideas' quality, but not quantity compared to the control (Hypothesis 3, see Figure 2 and Supplementary Figure 1). Whereas for the RAT measure, both the math and the control condition performed similarly. Hypothesis 3 could thus only be partly supported.

Moderation

We explored whether the effect of condition on divergent and convergent thinking was moderated by creative self-efficacy, fixed and growth mindset (Hypothesis 4), emotions at time 1, age, gender, student status and hours of video games played. The control group was coded as a reference group. In total, we performed 3 (DVs: fluency, originality, and RAT) × 10 (moderators: CSE, fixed and growth mindset, happy t1, excited t1, active t1, age, gender, student status, video games played) = 30 moderated regressions.[2]

Only the growth mindset significantly interacted with the condition in predicting convergent thinking (RAT), $p < 0.001$. Specifically, only participants with a lower growth mindset had a higher RAT score in the convergent thinking game compared to the control group, $p < 0.001$. In contrast, the difference between the two groups was not significant among those with a higher growth mindset, $p = 0.695$.

Mediation

Regarding emotions, participants who played the game that stimulated convergent thinking reported the highest *happiness* and *excitement* levels. In contrast, participants in the math condition reported the lowest *happiness* and *excitement* levels (Figures 5, 6). In contrast, we found no effect on *active* (Supplementary Figure 2). This—in parts—supports our Hypothesis 5.

Before testing whether the effect of conditions on creative performance is mediated by emotions (Hypothesis 6), we computed zero-order correlations between all variables. Interestingly, fluency, originality, and RAT were all uncorrelated with emotions and most other variables (Table 2). Therefore, we can reject Hypothesis 6 because the path between the mediator and the outcome is non-significant.

Control variables

Several variables were assessed as control variables to determine their possible influence on the relationships tested here: we assessed the age, gender (0 = men, 1 = women), and whether they are students (0 = no, 1 = yes) and video games played in hours per week (compare Table 2). We found small positive correlations for age, with older people showing higher RAT scores and assigning higher *activity* levels at t1. Otherwise, no meaningful correlations are found beyond the participants' descriptive: students tend to be younger, and males tend to play more video games.

Discussion

Our priming experiment investigated the impact of playing short games and solving arithmetic tasks on creative performances compared to a no-intervention. The results show that creativity, as operationalized through divergent and convergent thinking, is enhanced through the games, whereas math tasks lead to worse creative performance. Specifically, one of the games allowed for many potential solutions (divergent thinking condition), whereas the other required precise solutions (convergent thinking condition). In line with Hypothesis 2, we found that participants in the convergent thinking condition scored higher on a convergent thinking task. Interestingly, this positive priming effect was not achieved through the math tasks, even though mental arithmetic also leads to enhanced focused attention. This suggests that games are more engaging, resulting in a more open and creative mindset.

In comparison, the math condition reveals that a task that requires an intense focus leads to less creative performance, as it potentially primes a hyper-focused, closed mindset. As we only used a simple form of a math task, which is comparably easy but nevertheless cognitively demanding, our results need to be interpreted within this limited scope. Other mathematical tasks requiring more flexible thinking could potentially work as a prime for a flexible, creative mindset (Ismunandar et al., 2020).

We also found some intriguing effects of our interventions on emotions. Although participants in the math condition reported being less happy and less excited, this change in emotion was not the reason for their reduced creative performance. Overall, contrary to previous findings (Baas et al., 2008), emotions were unrelated to creative performance, as were CSE and the

2 Because of the large number of comparisons, we set the alpha-threshold to 0.003. In other words, only if $p < 0.003$ we consider a moderation to be significant. This number is in our view neither too conservative nor too liberal, as it balances correlated predictors with the number of comparisons. This approach follows Hanel et al. (2019).

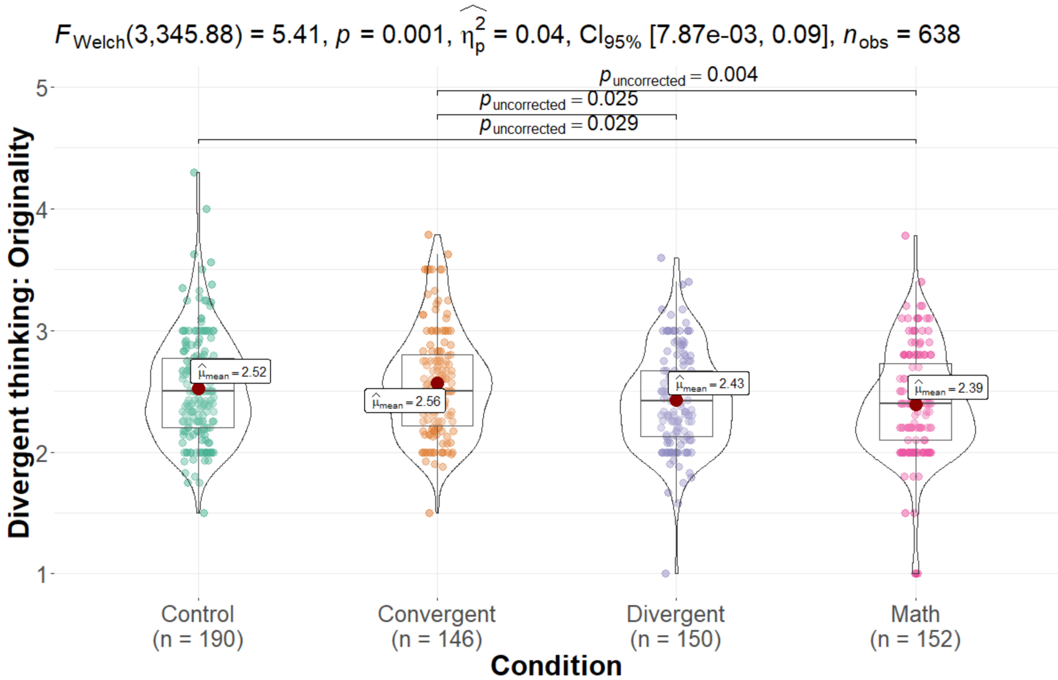

FIGURE 3
Effect of condition on divergent thinking (originality).

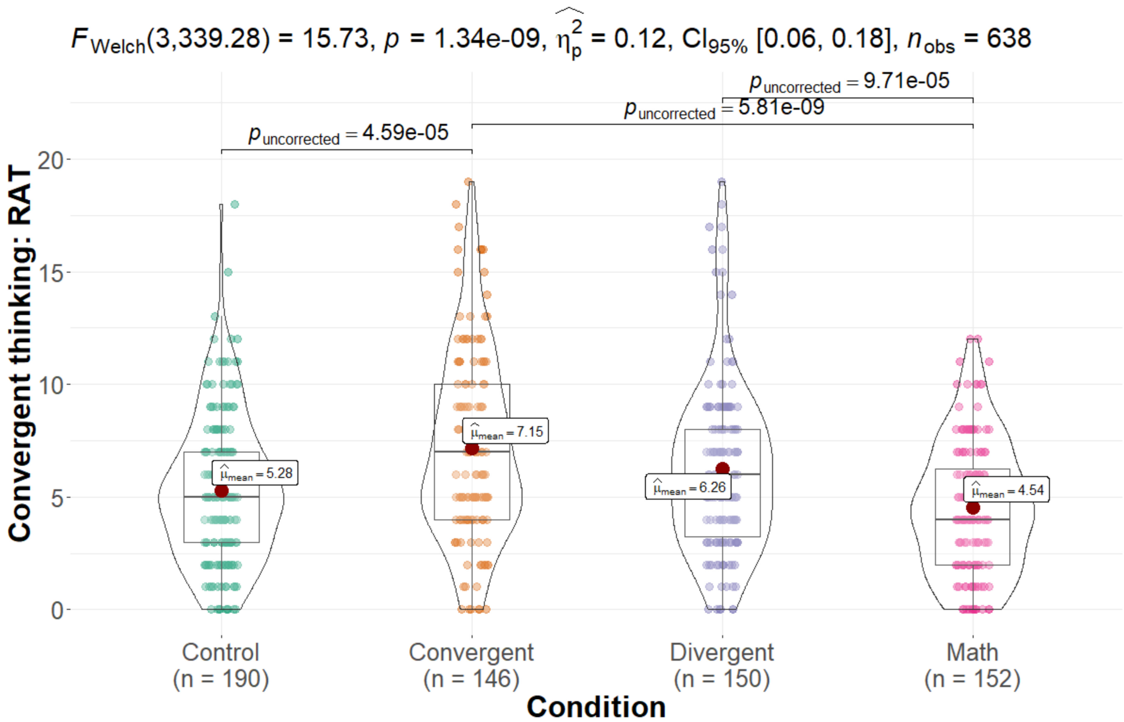

FIGURE 4
Effect of condition on convergent thinking (RAT).

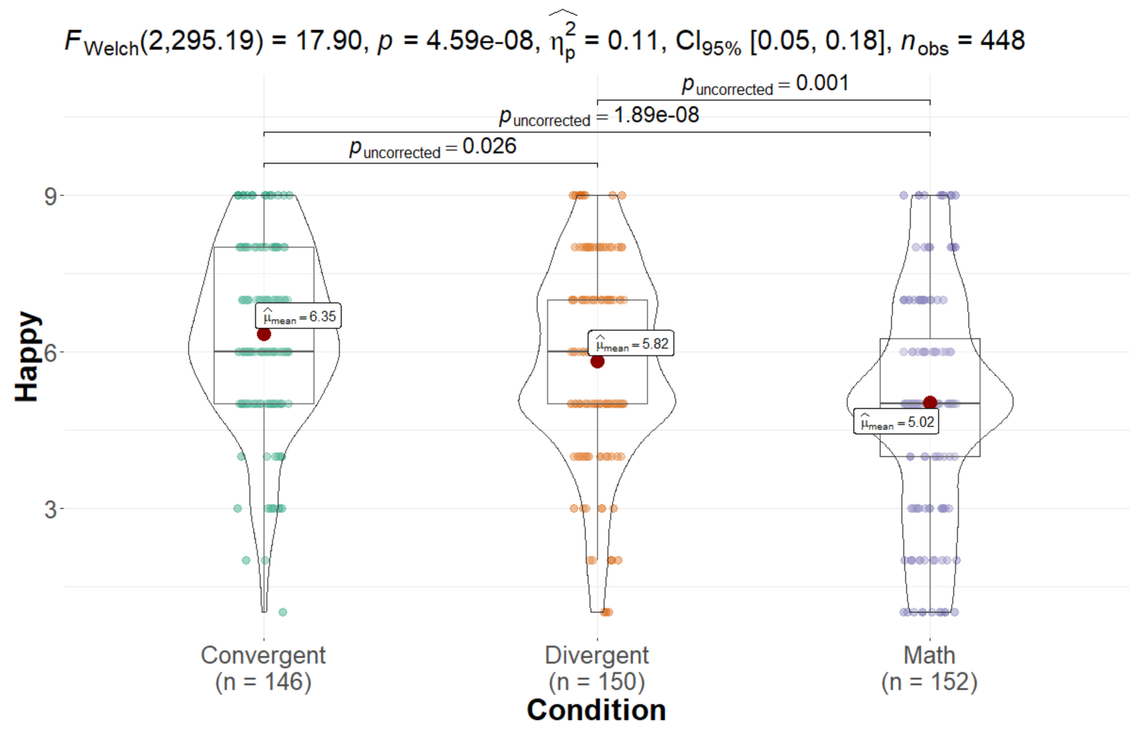

FIGURE 5
Effect of condition on happiness.

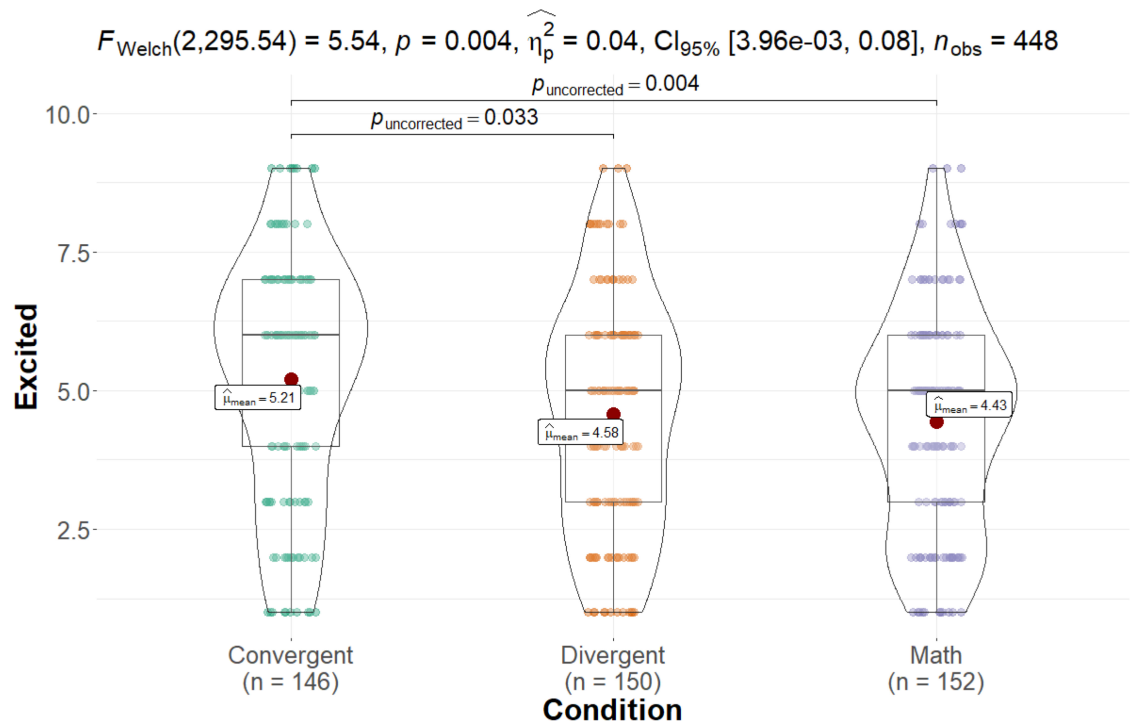

FIGURE 6
Effect of condition on excitement.

TABLE 2 Correlations between all variables.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Fluency															
2	Originality	0.07														
3	RAT	0.06	0.1*													
4	Happy t1	−0.02	0.03	−0.01												
5	Happy t2	−0.08	0.04	0.06	0.74***											
6	Excited t1	−0.02	0.02	−0.03	0.49***	0.47***										
7	Excited t2	0	−0.02	0	0.4***	0.51***	0.74***									
8	Active t1	−0.02	0.02	0.04	0.42***	0.41***	0.49***	0.43***								
9	Active t2	0.03	−0.01	−0.02	0.36***	0.44***	0.39***	0.55***	0.71***							
10	CSE	0.13**	0.03	0.09	0.19***	0.13	0.23***	0.19***	0.20***	0.13						
11	Fixed	−0.09	−0.06	−0.03	−0.01	0.01	0	0.01	0.02	−0.01	−0.3					
12	Growth	0.07	0.06	0.01	0.17***	0.18***	0.13***	0.14**	0.11**	0.15**	0.41***	−0.54***				
13	Age	−0.07	0.06	0.20***	0.07	0.06	0.02	0.04	0.18***	0.07	0.04	0.14**	−0.10*			
14	Gender	0.03	0.01	−0.05	0.09	0.03	0	−0.04	−0.03	−0.03	−0.03	0.08	−0.03	−0.07		
15	Student	0.07	−0.05	−0.05	−0.07	−0.10	−0.02	−0.08	−0.05	−0.01	0.11**	−0.11*	0.09	−0.23***	0.01	
16	Video games	−0.07	0.01	0.05	−0.07	−0.04	−0.05	−0.01	−0.05	0.02	−0.02	−0.02	0.02	−0.11*	−0.18***	0.08

RAT, Remote Associates Test; t1, before intervention; t2, after intervention; CSE, creative self-efficacy; Fixed & Growth, fixed and growth mindset. Gender: 0: men, 1: women, Meditation/Student: 0: no, 1: yes, video games: video games played in hours per week.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (all two-tailed).

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fixed- vs. growth mindset. However, the correlations between those measures align with the literature: CSE is positively associated with the growth mindset but uncorrelated with the fixed-mindset (e.g., Hass et al., 2016; Karwowski and Brzeski, 2017). This further supports the validity of our measures.

However, we found that a growth mindset moderated the association between convergent thinking vs. control condition and RAT: Only participants with a lower growth mindset scored higher on the convergent thinking task after participating in the convergent thinking game. Potentially, those with a more inferior growth mindset (who do not necessarily have to have a higher fixed mindset) can be more effectively primed as their creative potential is not yet utilized due to a rather negative self-perception. This is in line with other research, which found that participants with lower creative skills benefit more from creative training methods than individuals with advanced creative skills (e.g., Agnoli et al., 2018; Meinel et al., 2018).

Our analysis showed no effect of gender, age, or student status on creative performance. Also, the number of hours participants usually played online games was uncorrelated with their creative performance. This suggests that playing a short game can have priming effects but playing games over a more extended period of time does not necessarily lead to more creative performance. However, the data we have about their gaming habits is scarce, and we also do not know the kind of game they usually play. Based on the study based on *Minecraft* gameplay (Blanco-Herrera et al., 2019), games need to be very open and flexible to effect creative performance positively when played repeatedly.

Our findings provide further evidence that priming is an easy to implement and an effective way to alter human cognitive performance. As it is often unconscious, it does not require active engagement. Indeed, even minor situational conditions can act as a prime. For example, when studying the effects of remote work, Brucks and Levav (2022) found that simply looking at a screen, like a laptop, lowers our creative performance compared to similar interactions with the same person in the room. Another study used a more subtle achievement prime to elicit a creative mindset (Minas and Dennis, 2019): participants used special software for the creativity measures. The software presented visual banners with motivational slogans to prime achievement in one condition. This had a small but positive impact on the participants' creative test performance compared to those in the control condition not seeing such banners.

Seemingly small changes in the (digital) environment we interact with can directly affect our cognitive abilities. Putting our results into the context of digital learning scenarios enforces the need to cautiously design environments that support the thinking patterns relevant to the learning content. In the case of creativity, when students are required to develop ideas and solve problems in an online course, their performance could be enhanced through engaging games as used in our study. When students reach an open, flexible, and free-associative mindset, developing ideas and solutions is easier for them. Feedback on successful creative performance should improve a student's creative self-efficacy beliefs, contributing to a positive motivation for future creative tasks (Meinel et al., 2018). This creates a positive feedback loop that improves diverse aspects of students' creativity. Even students with a fixed creative mindset can be convinced of individual improvement with repeated feedback on their (even minor) performance improvements through practice (Dweck, 2008).

Limitations

As with every empirical approach, we face methodological issues, which require us to interpret our results cautiously. The order of the creativity tests was not balanced, potentially resulting in order effects. As the divergent thinking task came first, this could work as a prime for the convergent thinking task. However, as this is true for all three experimental conditions, this does not challenge our conclusions. Further, priming effects diminished over time, although it is unclear how strong a prime works and how long its impact can last (Sassenberg et al., 2022). Potentially, there are individual differences we have not considered. While we have not found an impact of regular gameplay on the creative performance of the participants, we cannot exclude the potential influence of different gameplay perceptions (and thus different prime effectiveness) based on regular gameplay. More studies are required on the relation between gameplay, games as primes, and subsequent creative performance.

Future directions and conclusion

Future research should investigate other gamified and game-based learning scenarios and their potential impact on creative performances. Our analysis used short and engaging games. However, the transferability to other games or aspects of games is uncertain. In addition, there are many aspects to be notorious around creative thinking, such as self-awareness beyond CSE, and also other more detailed aspects of divergent thinking. The use of alternative tests of creativity may provide further clues to specific interactions with games. Finally, extending our method to an educational design would be important: Are students less creative after math classes than after other subjects (e.g., history, languages)? This would have important implications for the structure of the class schedule.

Including games and gamified learning content in digital settings can benefit students' creative performances. Games can elicit an interactive, flexible, broad-associative mindset that facilitates creative thinking and problem-solving. In contrast, math tasks requiring a high concentration level tend to harm subsequent creative performance. Designers of digital learning environments should keep these connections in mind. Together, playing short games, for example, in brief breaks, can be an effective tool to enhance creative performance.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JH contributed to developing the study design, conduction, and manuscript preparation. PH contributed to the statistical analysis and the manuscript preparation. Both authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.976459/full#supplementary-material

References

Agnoli, S., Zanon, M., Mastria, S., Avenanti, A., and Corazza, G. E. (2018). Enhancing creative cognition with a rapid right-parietal neurofeedback procedure. *Neuropsychologia* 118, 99–106. doi: 10.1016/j.neuropsychologia.2018.02.015

Agogué, M., Levillain, K., and Hooge, S. (2015). Gamification of creativity: Exploring the usefulness of serious games for ideation. *Creat. Innov. Manage.* 24, 415–429. doi: 10.1111/caim.12138

Amabile, T. M. (1982). Social psychology of creativity: A consensual assessment technique. *J. Pers. Soc. Psychol.* 43:997.

Amabile, T. M., Barsade, S. G., Mueller, J. S., and Staw, B. M. (2005). Affect and creativity at work. *Administ. Sci. Quart.* 50, 367–403. doi: 10.2189/asqu.2005.50.3.367

Ashinoff, B. K. (2014). The potential of video games as a pedagogical tool. *Front. Psychol.* 5:1109. doi: 10.3389/fpsyg.2014.01109

Baas, M., De Dreu, C. K. W., and Nijstad, B. A. (2008). A meta-analysis of 25 years of mood-creativity research: Hedonic tone, activation, or regulatory focus? *Psychol. Bull.* 134, 779–806. doi: 10.1037/a0012815

Bechtoldt, M. N., Choi, H.-S., and Nijstad, B. A. (2012). Individuals in mind, mates by heart: Individualistic self-construal and collective value orientation as predictors of group creativity. *J. Exp. Soc. Psychol.* 48, 838–844.

Beeftink, F., Eerde, W., Rutte, C. G., and Bertrand, J. W. M. (2012). Being successful in a creative profession: The role of innovative cognitive style, self-regulation, and self-efficacy. *J. Bus. Psychol.* 27, 71–81. doi: 10.1007/s10869-011-9214-9

Behnamnia, N., Kamsin, A., Ismail, M. A. B., and Hayati, A. (2020). The effective components of creativity in digital game-based learning among young children: A case study. *Child. Youth Serv. Rev.* 116:105227. doi: 10.1016/j.childyouth.2020.105227

Birdi, K. S. (2005). No idea? Evaluating the effectiveness of creativity training. *J. Eur. Indust. Train.* 29, 102–111. doi: 10.1108/03090590510585073

Blanco-Herrera, J. A., Gentile, D. A., and Rokkum, J. N. (2019). Video games can increase creativity, but with caveats. *Creat. Res. J.* 31, 119–131. doi: 10.1080/10400419.2019.1594524

Bowden, E. M., and Jung-Beeman, M. (2003). Normative data for 144 compound remote associate problems. *Behav. Res. Methods Instruments Comput.* 35, 634–639. doi: 10.3758/BF03195543

Brucks, M. S., and Levav, J. (2022). Virtual communication curbs creative idea generation. *Nature* 605, 108–112.

Byrge, C., and Tang, C. (2015). Embodied creativity training: Effects on creative self-efficacy and creative production. *Thinking Skills Creat.* 16, 51–61.

Campion, M., and Levita, L. (2014). Enhancing positive affect and divergent thinking abilities: Play some music and dance. *J. Posit. Psychol.* 9, 137–145.

Cheng, M.-T., Huang, W.-Y., and Hsu, M.-E. (2020). Does emotion matter? An investigation into the relationship between emotions and science learning outcomes in a game-based learning environment. *Br. J. Educ. Technol.* 51, 2233–2251. doi: 10.1111/bjet.12896

Chiu, T. K. F., Lin, T.-J., and Lonka, K. (2021). Motivating online learning: the challenges of COVID-19 and beyond. *Asia-Pacific Educ. Res.* 30, 187–190. doi: 10.1007/s40299-021-00566-w

Chung, T. (2013). Table-top role playing game and creativity. *Think. Skills Creat.* 8, 56–71. doi: 10.1016/j.tsc.2012.06.002

Colzato, L. S., Szapora, A., and Hommel, B. (2012). Meditate to create: The impact of focused-attention and open-monitoring training on convergent and divergent thinking. *Front. Psychol.* 3:116. doi: 10.3389/fpsyg.2012.00116

Cropley, A. (2006). In praise of convergent thinking. *Creat. Res. J.* 18, 391–404. doi: 10.1207/s15326934crj1803_13

DeCoster, J., and Claypool, H. M. (2004). A meta-analysis of priming effects on impression formation supporting a general model of informational biases. *Personali. Soc. Psychol. Rev.* 8, 2–27. doi: 10.1207/S15327957PSPR0801_1

Dennis, A. R., Minas, R. K., and Bhagwatwar, A. P. (2013). Sparking creativity: Improving electronic brainstorming with individual cognitive priming. *J. Manage. Inform. Syst.* 29, 195–216. doi: 10.2753/MIS0742-1222290407

Dreu, C. K. W. D., Nijstad, B. A., and Baas, M. (2010). Behavioral activation links to creativity because of increased cognitive flexibility. *Soc. Psychol. Personali. Sci.* 2, 72–80. doi: 10.1177/1948550610381789

Dweck, C. S. (2008). *Mindset: The new psychology of success*. New York, NY: Random HouseDigital Inc.

Dyson, S. B., Chang, Y.-L., Chen, H.-C., Hsiung, H.-Y., Tseng, C.-C., and Chang, J.-H. (2016). The effect of tabletop role-playing games on the creative potential and emotional creativity of Taiwanese college students. *Think. Skills Creat.* 19, 88–96.

Faul, F., Erdfelder, E., Buchner, A., and Lang, A.-G. (2009). Statistical power analyses using G*power 3.1: Tests for correlation and regression analyses. *Behav. Res. Methods* 41, 1149–1160. doi: 10.3758/BRM.41.4.1149

Galinsky, A. D., Moskowitz, G. B., and Skurnik, I. (2000). Counterfactuals as self-generated primes: The effect of prior counterfactual activation on person perception judgments. *Soc. Cogn.* 18, 252–280.

Glăveanu, V. P. (2018). Educating which creativity? *Think. Skills Creat.* 27, 25–32. doi: 10.1016/j.tsc.2017.11.006

Glăveanu, V., Hanson, M. H., Baer, J., Barbot, B., Clapp, E. P., Corazza, G. E., et al. (2019). Advancing creativity theory and research: A socio-cultural manifesto. *J. Creat. Behav.* 2019:395. doi: 10.1002/jocb.395

Gollwitzer, P. M., Heckhausen, H., and Steller, B. (1990). Deliberative and implemental mind-sets: Cognitive tuning toward congruous thoughts and information. *J. Personali. Soc. Psychol.* 59:1119.

Haase, J. (2020). "How games spoil creativity: A creative mindset priming study," in *Proceedings of the ISPIM conference proceedings*, (Manchester: ISPIM).

Haase, J., Hoff, E. V., Hanel, P. H. P., and Innes-Ker, Å (2018). A meta-analysis of the relation between creative self-efficacy and different creativity measurements. *Creat. Res. J.* 30, 1–16. doi: 10.1080/10400419.2018.1411436

Haase, V. G., Guimarães, A. P. L., and Wood, G. (2019). "Mathematics and emotions: the case of math anxiety," in *International Handbook of Mathematical Learning Difficulties: From the Laboratory to the Classroom*, eds A. Fritz, V. G. Haase, and P. Räsänen (Springer International Publishing), 469–503. doi: 10.1007/978-3-319-97148-3_29

Halbrook, Y. J., O'Donnell, A. T., and Msetfi, R. M. (2019). When and how video games can be good: A review of the positive effects of video games on well-being. *Perspect. Psychol. Sci.* 14, 1096–1104. doi: 10.1177/1745691619863807

Hanel, P. H. P., Zarzeczna, N., and Haddock, G. (2019). Sharing the same political ideology yet endorsing different values: Left-and right-wing political supporters are more heterogeneous than moderates. *Soc. Psychol. Personali. Sci.* 10, 874–882. doi: 10.1177/1948550618803348

Hass, R. W., Katz-Buonincontro, J., and Reiter-Palmon, R. (2016). Disentangling creative mindsets from creative self-efficacy and creative identity: Do people hold fixed and growth theories of creativity? *Psychol. Aesthe. Creat. Arts* 10, 436–446. doi: 10.1037/aca0000081

Hernández, M., and Moreno, J. (2018). A systematic literature review on organizational training using game-based learning. *Iberoamerican Workshop Hum. Comput. Int.* 2018, 1–18.

Howard-Jones, P. A., and Jay, T. (2016). Reward, learning and games. *Curr. Opin. Behav. Sci.* 10, 65–72.

Ismunandar, D., Gunadi, F., Taufan, M., and Mulyana, D. (2020). Creative thinking skill of students through realistic mathematics education approach. *J. Phys. Conf. Seri.* 1657:012054. doi: 10.1088/1742-6596/1657/1/012054

Jensen, L. X., Bearman, M., and Boud, D. (2021). Understanding feedback in online learning – a critical review and metaphor analysis. *Comput. Educ.* 173:104271. doi: 10.1016/j.compedu.2021.104271

Karwowski, M. (2014). Creative mindsets: Measurement, correlates, consequences. *Psychol. Aesthe. Creat. Arts* 8, 62–70. doi: 10.1037/a0034898

Karwowski, M., and Brzeski, A. (2017). "Creative mindsets: Prospects and challenges," in *The creative self*, eds M. Karwowski and J. C. Kaufman (Amsterdam: Elsevier), 367–383. doi: 10.1016/B978-0-12-809790-8.00021-2

Koivisto, J., and Hamari, J. (2019). The rise of motivational information systems: A review of gamification research. *Int. J. Inform. Manage.* 45, 191–210.

Kray, L. J., Galinsky, A. D., and Wong, E. M. (2006). Thinking within the box: The relational processing style elicited by counterfactual mind-sets. *J. Personali. Soc. Psychol.* 91:33. doi: 10.1037/0022-3514.91.1.33

Li, Y., Xu, Z., Hao, Y., Xiao, P., and Liu, J. (2022). Psychosocial impacts of mobile game on K12 students and trend exploration for future educational mobile games. *Front. Educ.* 7:843090. doi: 10.3389/feduc.2022.843090

Lorist, M. M., Klein, M., Nieuwenhuis, S., De Jong, R., Mulder, G., and Meijman, T. F. (2000). Mental fatigue and task control: Planning and preparation. *Psychophysiology* 37, 614–625.

Maddux, W. W., Adam, H., and Galinsky, A. D. (2010). When in rome. learn why the romans do what they do: How multicultural learning experiences facilitate creativity. *Personali. Soc. Psychol. Bull.* 36, 731–741. doi: 10.1177/0146167210367786

Massar, S. A. A., Csathó, Á, and Van der Linden, D. (2018). Quantifying the motivational effects of cognitive fatigue through effort-based decision making. *Front. Psychol.* 9:843. doi: 10.3389/fpsyg.2018.00843

Meinel, M., Wagner, T. F., Baccarella, C. V., and Voigt, K.-I. (2018). Exploring the effects of creativity training on creative performance and creative self-efficacy: Evidence from a longitudinal study. *J. Creat. Behav.* 53, 546–558. doi: 10.1002/jocb.234

Minas, R. K., and Dennis, A. R. (2019). Visual background music: creativity support systems with priming. *J. Manage. Inform. Syst.* 36, 230–258. doi: 10.1080/07421222.2018.1550559

Newton, D. P. (2013). Moods, emotions and creative thinking: A framework for teaching. *Think. Skills Creat.* 8, 34–44. doi: 10.1016/j.tsc.2012.05.006

Ninaus, M., Greipl, S., Kiili, K., Lindstedt, A., Huber, S., Klein, E., et al. (2019). Increased emotional engagement in game-based learning – a machine learning approach on facial emotion detection data. *Comput. Educ.* 142:103641. doi: 10.1016/j.compedu.2019.103641

Pavlas, D., Heyne, K., Bedwell, W., Lazzara, E., and Salas, E. (2010). Game-based learning: The impact of flow state and videogame self-efficacy. *Proc. Hum. Fact. Ergon. Soc. Ann. Meet.* 54, 2398–2402.

Plass, J. L., Homer, B. D., and Kinzer, C. K. (2015). Foundations of game-based learning. *Educ. Psychol.* 50, 258–283.

Reiter-Palmon, R., Forthmann, B., and Barbot, B. (2019). Scoring divergent thinking tests: A review and systematic framework. *Psychol. Aesthe. Creat. Arts* 13:144.

Runco, M. A., and Acar, S. (2012). Divergent thinking as an indicator of creative potential. *Creat. Res. J.* 24, 66–75. doi: 10.1080/10400419.2012.652929

Sadler-Smith, E. (2015). Wallas' four-stage model of the creative process: More than meets the eye? *Creat. Res. J.* 27, 342–352. doi: 10.1080/10400419.2015.1087277

Sailer, M., Murböck, J., and Fischer, F. (2021). Digital learning in schools: What does it take beyond digital technology? *Teach. Teacher Educ.* 103:103346. doi: 10.1016/j.tate.2021.103346

Sassenberg, K., and Moskowitz, G. B. (2005). Don't stereotype, think different! Overcoming automatic stereotype activation by mindset priming. *J. Exp. Soc. Psychol.* 41, 506–514. doi: 10.1016/j.jesp.2004.10.002

Sassenberg, K., Moskowitz, G. B., Fetterman, A., and Kessler, T. (2017). Priming creativity as a strategy to increase creative performance by facilitating the activation and use of remote associations. *J. Exp. Soc. Psychol.* 68, 128–138.

Sassenberg, K., Moskowitz, G. B., Jacoby, J., and Hansen, N. (2007). The carry-over effect of competition: The impact of competition on prejudice towards uninvolved outgroups. *J. Exp. Soc. Psychol.* 43, 529–538.

Sassenberg, K., Winter, K., Becker, D., Ditrich, L., Scholl, A., and Moskowitz, G. B. (2022). Flexibility mindsets: Reducing biases that result from spontaneous processing. *Eur. Rev. Soc. Psychol.* 33, 171–213. doi: 10.1080/10463283.2021.1959124

Scott, G., Leritz, L. E., and Mumford, M. D. (2004a). The effectiveness of creativity training: A quantitative review. *Creat. Res. J.* 16, 361–388.

Scott, G., Leritz, L. E., and Mumford, M. D. (2004b). Types of creativity training: Approaches and their effectiveness. *J. Creat. Behav.* 38, 149–179.

Slepian, M. L., Weisbuch, M., Rutchick, A. M., Newman, L. S., and Ambady, N. (2010). Shedding light on insight: Priming bright ideas. *J. Exp. Soc. Psychol.* 46, 696–700. doi: 10.1016/j.jesp.2010.03.009

Steidle, A., and Werth, L. (2013). Freedom from constraints: Darkness and dim illumination promote creativity. *J. Environ. Psychol.* 35, 67–80. doi: 10.1016/j.jenvp.2013.05.003

Sternberg, R. J. (1999). *Thinking Styles*. Cambridge: Cambridge University Press.

Stolaki, A., and Economides, A. A. (2018). The creativity challenge game: an educational intervention for creativity enhancement with the integration of information and communication technologies (ICTs). *Comput. Educ.* 123, 195–211.

Subhash, S., and Cudney, E. A. (2018). Gamified learning in higher education: A systematic review of the literature. *Comput. Hum. Behav.* 87, 192–206. doi: 10.1016/j.chb.2018.05.028

Tan, A.-G., Ho, V., Ho, E., and Ow, S. (2008). High school students' perceived creativity self-efficacy and emotions in a service learning context. *Int. J. Creat. Problem Solving* 18, 115–126.

Tierney, P., and Farmer, S. M. (2002). Creative self-efficacy: Its potential antecedents and relationship to creative performance. *Acad. Manage. J.* 45, 1137–1148.

Torrance, E. P. (1972). Predictive validity of the Torrance tests of creative thinking. *J. Creat. Behav.* 6, 236–262.

van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., and de Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Comput. Hum. Behav.* 72, 577–588. doi: 10.1016/j.chb.2017.03.010

Wang, X., Lu, K., Runco, M. A., and Hao, N. (2018). Break the "wall" and become creative: Enacting embodied metaphors in virtual reality. *Conscious. Cogn.* 62, 102–109. doi: 10.1016/j.concog.2018.03.004

Zatarain Cabada, R., Barrón Estrada, M. L., Ríos Félix, J. M., and Alor Hernández, G. (2020). A virtual environment for learning computer coding using gamification and emotion recognition. *Int. Learn. Environ.* 28, 1048–1063. doi: 10.1080/10494820.2018.1558256