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Creativity as Key Trigger to Cognitive Achievement: Effects of Digital and Analog Learning Interventions

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Abstract
This study analyses the coherent integration of creativity into science education modules for eighth-grade students to enhance competence development. The learning modules' content covered a basic ecological unit about forests, applied as digital or analog lesson. By utilizing the creativity subscales 'Act' and 'Flow' its analysis resulted in a clear factorial structure. Notably, higher levels of creativity were associated with increased cognitive learning achievements among students, irrespective of the instructional delivery method—be it analog or digital. Particularly, the 'Act' and 'Flow' dimensions exhibited a promising potential for augmenting learning outcomes in learner-centric, gamified modules. The mentoring role of teachers is supposed to promote a flow state and simultaneously to highlight the significance of autonomy in learning processes. Unexpectedly, there were no discernible gender differences. This research significantly contributes to our understanding of the interplay among creativity, learning success, and instructional modalities within the realm of science education.

Keywords Creativity · Gamification · Digital learning · Act · Flow · Cognitive achievement

Introduction

The promotion of creativity in classrooms, alongside other associated personality attributes, is increasingly coming into focus on competence development (e.g. in Germany, KMK, 2020). Creativity is considered as a facilitator for knowledge acquisition, application, and transfer, contributing to innovation and nurturing individual curiosity (Lewis, 2009). The integration of creativity into science instructions holds promise for a more enduring approach to managing knowledge acquisition during learning processes (Henriksen et al.,

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2016). Despite recommendations from authors such as Wyse and Ferrari (2015), who primarily advocated for creativity integration in arts-related disciplines, it is imperative to extend this integration to other pertinent subjects, such as science, to address its underrepresentation in curricula (Robinson, 2011). According to Conradty & Bogner, 2018, the STEAM (STEM & Arts) approach can enhance cognitive abilities that are transferable to various life domains, notably in scientific research, where it enables the reframing of issues and the generation of solutions through unforeseen insights (DeHaan, 2011).

Furthermore, when discussing the nature of science, creativity is seen as a key characteristic of scientists and scientific work (Khishfe & Lederman, 2007). It becomes evident that a standardized and conformity-oriented system does not contribute to making society more adaptable and diverse (Robinson, 2011).

Current students are growing up in a digitized world, where access to and confrontation with seemingly endless information and social media is omnipresent. Consequently, they demand rapid responses, social interaction, and experiential learning even within the school environment (Anastasiadis et al., 2018). As a result, enthusiasm for conventional teaching methods is increasingly limited among the young ones. Their concept of an effective learning environment differs significantly from the ones of previous generations. To meet these evolving needs of students, an increasing number of studies are exploring innovative, more motivating, and entertaining approaches, such as gamification or even game-based learning. While gamification incorporates playful elements into a learning setting, game-based learning goes further by integrating learning content into a gaming environment. However, the boundaries between these two approaches are fluid. Studies of Pozo-Sánchez and colleagues (2022) recommend the integration of gamification in education as supportive, for example, via methods such as Escape Rooms. This can potentially enhance understanding of educational content and, consequently, support academic achievement. It may also enhance a range of skills and foster creativity. Anastasiadis and colleagues (2018) name additional benefits of digital game-based learning, including its positive impact on cognitive development and digital literacy, social-emotional growth, the cultivation of soft skills, improved decision-making and problem-solving capabilities, as well as the promotion of critical thinking. Furthermore, it is supposed to create an improved environment for collaboration and communication, fosters a positive competitive atmosphere, boosts self-esteem and autonomy, enables progressive learning through experience, and provides a rewarding sense of progress and success (Anastasiadis et al., 2018). The integration with other learning methods, such as cooperative learning, problem-based learning, and project-based learning, could further elevate and enrich the overall learning experience for students.

Theoretical Background

We utilized the empirical instrument "Cognitive Processes Associated with Creativity," abbreviated as CPAC (Miller & Dumford, 2016), a tool substantially refined by Conradty & Bogner, 2018 and initially applied in informal science education programs (Conradty & Bogner, 2019). Through this instrument, our aim is to quantitatively assess students' creativity within science education environments, with particular emphasis on the "Act" and "Flow" subscales. "Act" involves taking deliberate steps or engaging in actions to manifest ideas or intentions. When someone acts, a process of "flow" can be initiated, where the attention of the acting person becomes fully absorbed in the task, leading to a state of heightened focus and immersion (Csíkszentmihályi, 2000). This state of flow fosters “creativity”, as it allows for the uninhibited expression of ideas, the exploration of novel solutions, and the synthesis of new connections, ultimately leading to the generation of innovative outcomes. Therefore, the causal connection between “act,” “flow,” and “creativity” lies in the active engagement that catalyzes the flow state, which in turn nurtures and enhances creative thinking and expression (Csíkszentmihályi, 2000).

The theoretical background for the creativity approach is considered highly complex and challenging to define (Corazza, 2016; Plucker & Renzulli, 1999). For this study, we adopted the definition of creativity within the educational setting as delineated by Henriksen et al. (2016). They describe creativity as novel and effective, with a subtler component of wholeness. Their definition delves even deeper, incorporating “person,” “field,” and “domain” as crucial components, albeit individually insufficient. It is the interactions that give rise to a dynamic process, which they define as creativity. The increasing importance attributed to research on creativity underscores the acknowledgment of the essentiality of cultivating creative thinking in a competency-driven and forward-thinking society (Corazza, 2016). In today’s information-rich landscape, individuals are inundated with data on a regular basis, and the ability to effectively convert this information into knowledge demands a creative approach (Chua, 2015). Perry-Smith (2014) conceived a creativity-enhancing environment that could be adapted for use in science education. Social interaction and communication are crucial in fostering a diverse and imaginative work atmosphere, which, in turn, can promote creativity. As a result, creativity has the potential to promote innovation, which holds significant importance from both economic and social viewpoints (Perry-Smith, 2014). Creativity should therefore also contribute to generating solutions for the transformation of today’s societies towards sustainable systems, taking into account economic, social as well as ecological perspectives. Innovation entails the creation of effective and fresh solutions to challenges, necessitating creative problem-solving strategies (Aldous, 2007). Livingston (2010) argues that creativity is essential for developing content knowledge and skills within an inquiry-based culture that values investigation, collaboration, connection, integration, and synthesis, thereby enhancing problem-solving abilities for all students. In the context of 21st-century learning, creativity should be prioritized in education, as it prepares learners to navigate the unknown and adapt to new situations (Collard & Looney, 2014). Unfortunately, current educational policies and attempts to standardize the school system have inadvertently stifled creativity instead of fostering it (Kupers et al., 2018). As a result, educators must find ways to promote creativity, particularly in science classrooms, to ensure that graduates can meet the demands of a globalized and innovative economy (Henriksen et al., 2016). While creativity undoubtedly holds significance across various domains, the focus of this paper is primarily on its role within the field of science. Richards and Cotterall (2016) provide guidelines to assist teachers in establishing creativity within the classroom. Although collaborative learning approaches require diverse teaching techniques (Yager, 2000) and adequate teacher training to sustain creative processes in science (Sawyer, 2006), some researchers suggest that forced group work may hinder creative thinking (Csíkszentmihályi, 2000; Schmidt, 2011). Most importantly, extrinsic motivators, such as evaluating work or creating situations purely focused on exams, should be avoided. Despite being common practices in schools, they can have a detrimental effect on creative processes (Amabile, 1983; Baer, 1997).

Scholarly discourse frequently explores the topic of gender disparities in creative cognition within the context of science disciplines. Okere and Ndeke (2012) uncovered notable variances between genders pertaining to dimensions of scientific creativity such as flexibility, strategizing, and the discernment of relational patterns. On the contrary, a body of research identifies no substantial dichotomies linked to gender in broader measures of creative capacity (Charyton et al., 2011; Charyton & Snelbecker, 2007). One potential explanation for these varying outcomes might be the preference of males and females for scientific subjects rather than creativity per se (Roth et al., 2022b). Global educational trends observed in studies like the Trends in International Mathematics and Science Study (TIMSS) support the notion of gender-related differences in scientific comprehension. Historically, male students have outperformed their female counterparts in many scientific areas and have shown a heightened inclination towards these subjects. Nevertheless, the TIMSS 2019 assessment revealed scenarios where female students outshined male students, particularly in experimental tasks that did not include explicit procedural guidance, as well as in a multitude of scientific fields that require robust argumentation and the practical implementation of theoretical knowledge (Mullis et al., 2020). These insights, should they be confirmed, suggest a potential linkage between creativity and intrinsic motivation. A deep-rooted passion for a specific discipline may indirectly influence one's capability for scientific reasoning and the capacity for creative thought. The diminishing gender gap identified in the TIMSS data suggests that previously observed gender-specific differences in creativity may be attributed to societal and cultural influences rather than inherent aptitudes. For instance, small gender differences favoring boys in science were noted in countries such as the USA, Hungary, Italy, and Singapore, whereas larger differences favoring girls were observed in Middle Eastern countries such as Saudi Arabia, Kuwait, Oman, and Bahrain. This lack of uniformity in gender differences in science achievement challenges the notion of large innate differences in quantitative reasoning, instead highlighting the influence of sociocultural factors. Considering the altered approach and heightened awareness, it might have become increasingly challenging to substantiate the gender differences that were consistently present in the 1970s and 1980s. Still, such disparity in findings suggests that the relationship between gender and creativity in scientific domains may be complex and warrants further investigation to understand underlying factors and potential influences.

The interplay of social background, working climate, and pedagogical experiences plays a crucial role in either promoting or inhibiting creative potential. Notably, a proclivity for perfectionism may engender an undue emphasis on attaining predefined goals, steering individuals toward rigid, ritualized methodologies aimed at circumventing errors (Grant et al., 2012). This may culminate in an atmosphere rife with anxiety, disenchantment, and an escalation of failings and recurrent setbacks (Grant et al., 2012) assigning fault for missteps is instrumental in averting such detrimental outcomes (Conradty & Bogner, 2018). It is vital to acknowledge that diverse factors may act as catalysts or barriers to creative thought (Conradty et al., 2020). For example, Sosa (2011) mentioned social distance, such as during the Covid-19 pandemic, as inhibiting creative expression. Conversely, the presence of a cohesive team dynamic may inadvertently encourage self-censorship or cause the suppression of innovative ideas due to apprehensions of deviating from the norm (Conradty & Bogner, 2018). Additionally, the dichotomy between work and leisure can also impact creativity; Csíkszentmihályi (2000) posited that integrating playfulness into tasks might auspiciously precipitate the genesis of novel concepts.

Flow, recognized as an integral aspect of creativity, is identified as a hallmark of effective game design. Games are at their most engaging when they catalyze the state of flow, drawing the player into a realm of intense focus, deep enjoyment, and a sense of immersive engagement with the activity (Johnson & Wiles, 2003). However, it still needs to be questioned if this consequently applies to gamified learning. Silva et al. (2019) propose that gamified tools may bolster students' motivation and immersion, suggesting that gaming strategies could be a potent conduit for academic learning. Complementary evidence from another study posits that gamification enhances the experience of flow, which correlates with heightened enjoyment, motivation, and potentially augments cognitive learning outcomes (Silva et al., 2021). Moreover, the comprehensive analysis by Zainuddin et al. (2020) underscores that while gamification in pedagogy activates motivation, engagement, and social interaction, it also encounters specific challenges and obstacles. Research by Pozo-Sanchez et al. (2022) indicates that both virtual and in-person escape rooms deployed in higher education settings can stimulate fun, exploratory behavior, and creative thinking. Kuo et al. (2022) accentuate that escape rooms integrating both digital and physical elements can considerably uplift students' creative thinking and learning motivation, yet they do not appear to exert a significant effect on scientific academic performance.

Considering these factors, we have developed two gamified interventions – one entirely digital and one analog escape game ("EduBreakout") – to examine the relationship between learning and creativity. The following questions are to be answered: (1) Is the shortened CPAC questionnaire suitable for use with 8th-grade students? (2) Are there gender-specific differences in creativity and its association with learning outcomes? (3) How do creativity and game-based learning impact learning success among students? (4) Are there differences between the digital and the analog intervention groups?

Materials and Methods

Research Sample

A total of 393 eighth-grade students participated in our study, all attending college preparatory secondary schools ("Gymnasium") in Bavaria, Germany. Schools from both urban and rural areas were included. Enrollment occurred as teachers registered their classes for our instructional module, obtaining informed consent from students and parents. Due to logistical considerations, including the high material costs associated with the analog intervention and limited in-person instruction during the COVID-19 pandemic, the decision to participate in either the analog (control, $n=93$) or digital ($n=300$) learning module was randomly determined on a school-by-school basis without any knowledge about the students (e.g. social background, etc.). Additionally, our study primarily focused on the effects of the digital intervention, which is a common approach in scientific research where the control group is smaller than the experimental group. Consequently, the uneven sample sizes (analog, $n=93$; digital, $n=300$) were deemed appropriate for the aims of our study and the practical constraints we faced.

Test Design and Data Analysis

All students filled out digital questionnaires that were anonymized comprising 25 multiple-choice items to assess their knowledge of the forest ecosystem and conservation (e.g. "Abiotic factors are, for example, …" with three distractors […predators and concurrents.; … minerals and food.; … humans and industry.] and one correct answer [… water and light.]). The knowledge questionnaires were administered thrice: the pre-test (T1) up to two weeks before the learning module, the post-test (T2) immediately following the intervention, and the retention test (T3) approximately six to nine weeks later. Additionally, the shortened creativity scale, consisting of 12 items used in previous studies (Conradty & Bogner, 2018; Roth et al., 2022b), on a four-point Likert scale, was employed in conjunction with the knowledge pre-test.

Based on the two cognitive factors of the creativity scale described in the literature, we conducted a confirmatory factor analysis using SPSS (Version 29.0). After examining items, we constructed a corresponding structural equation model in AMOS. Using t-tests (equal variance t-test), we investigated the manifestation of the cognitive factors "Act" and "Flow" concerning gender differences. Finally, correlation analyses were employed to explore potential associations between the expressions of "Act" and "Flow" and the participants' learning outcomes. Additionally, we examined potential differences in correlations between the two intervention groups in this regard using correlation analysis of the cognitive factors "Act" and "Flow" with the knowledge differences between pre- and retention tests. Previous to our calculation, we conducted a t-test with (using a bootstrapping procedure on the basis of 1000 repetitions and bias-corrected and accelerated [BCa] 95% confidence intervals) to validate the comparability of the two subsamples (digital and analog) on the knowledge pre-test.

The Learning Modules

The study involved two instructional modules, framed as "Edu Breakouts"—a pedagogical adaptation of escape games—designed to be completed over four lessons, which could be administered in either a single extended session or two double-lesson blocks. Although both modules presented the same content, about the forest ecosystem, human impact, and sustainability, they diverged in their preparatory processes: one was rooted in traditional, analog methods, while the other embraced a digital framework. These short-term interventions sought to encapsulate a complete teaching unit of the curriculum, encouraging students to engage autonomously in learning activities, either individually or in self-selected pairs or small groups. Throughout the modules, learners were poised to navigate any educational hurdles that emerged, with the teacher facilitating discussions to collectively overcome these obstacles.

The analog adaptation of the instructional module emulated a traditional station learning format, with each station dedicated to a distinct subtopic and characterized by a gamification element that was primarily executed using non-digital resources. To optimize the learning process, nine thematic stations were provided in duplicate. An accompanying workbook guided learners through the activities. As different stations addressed discrete conceptual dimensions, they were designed to be tackled independently of one another. The array of activities ranged from conducting experiments and documenting results to engaging in discourse and appraisal of forest management choices. Through engaging in a series of inquiry-driven assignments, students decrypted codes at each station, which, upon successful completion, provided access to a chest bestowing a modest incentive. For the purpose of fostering autonomy in learning, stations were equipped with exemplar solutions to support self-guided and self-regulated progression through the tasks.

Conversely, the digital iteration of the module imbued the learning experience with an element of play by enveloping students in an adventure-themed narrative. Utilizing tablets or computers, participants embarked on a journey through a series of websites, each hosting diverse educational games that composed the substance of the exercises. While hands-on activities such as experiments were not practicable in this format, the findings of such experiments were dynamically illustrated using an interactive pinboard equipped with H5P applications. This digital pedagogical approach placed a stronger emphasis on the critical analysis and interpretation of data, as opposed to the hands-on conduct and meticulous recording of experiments. Moreover, group discourse was not mandated within this framework. Learners were empowered to progress at their individual pace, working through the narrative on personal devices. Advancement within the storyline necessitated the resolution of challenges that unlocked codes, which then permitted access to the next segment of the tale by opening virtual doors or revealing concealed items. Unlike its analog counterpart, the digital version did not contain any handwritten assignments or backups, and the conclusion of the story varied depending on the students' decisions. This included an epilogue that depicted the outcomes of their choices. Thus, the two interventions had the same topic, but used specific methodological advantages of digital or analog learning. For further information about the learning modules see Fleissner-Martin and Bogner (2024) or Fleissner-Martin, et al. (2023).

Results

Analysis of the Abbreviated CPAC Scale

Our confirmatory factor analyses (CFA) predominantly mirrored the anticipated constructs of the CPAC (Cognitive Processes Associated with Creativity) structure, as documented in the literature (e.g., Conradty & Bogner, 2018). However, not all observed variables sufficiently captured the latent constructs of "*act*" and "*flow*" in the shortened creativity scale. One item did not load on any of the two factors (refer to Table 1). Consequently, this item ("*I asked other people to help generate potential solutions to a problem.*") was excluded from subsequent calculations. Similarly, the item "*While working on something*, *I try to generate as many ideas as possible*.", which exhibited a cross-loading exceeding ± 0.3, was also omitted. After removing these two items, a revised confirmatory factor analysis yielded five clearly assigned items for each of the two factors (see Table 1). The allocation of items aligns with the "*act*" and "*flow*" factors described in the literature (Conradty & Bogner, 2018, Miller & Dumford, 2016; Roth et al., 2022b). *Cronbach's alpha (α)* for the creativity scale yielded a value of 0.778, thereby confirming the scale's acceptability in terms of reliability as per the criteria established by Lienert and Raatz (1998). Additionally, the factor loadings delineated in the pattern matrix (Table 1) cumulatively resulted in a Kaiser-Meyer-

Table 1 Confirmatory factor analysis of the cognitive processes Associated with Creativity Scale (valid $N=393$)

Pattern Matrix[a]	Components of the Revised Factor Analysis 10	
Item	1	2
When I am intensely working, I do not like to stop.	0.813	
I was fully immersed in my work on a problem or task.	0.606	
I lost track of time when intensely working.	0.656	
If I am intensely working, I am fully aware of "the big picture".	0.585	
While working on something I enjoy, the work feels automatic and effortless.	0.502	
I incorporated a previously used solution in a new way.		0.794
I made a connection between a current problem or task and a related situation.		0.769
I joined together dissimilar concepts to create a novel idea.		0.628
Imagining potential solutions to a problem leads to new insights.		0.547
I looked at a problem or task from a different angle to find a solution.		0.546

Extraction method: Main component analysis

Rotation method: Oblimin with Kaiser normalization

a. The rotation is converged into 9 iterations

Total eigenvalue explained for 2 factors: 46.01%

Table shows factor loadings $>\pm 0.3$, Cronbach's alpha $=0.778$

Olkin (*KMO*) measure of sampling adequacy of 0.844, signifying that the factors extracted are both reliable and distinct, in alignment with the standards set by Kaiser (1970).

We fitted a structural equation model to validate the abbreviated scale and its two primary constructs – "*act*" and "*flow*" – in alignment with previous investigations such as Conradty & Bogner, (2018). In addition, we incorporated learning success as manifest variables: "Sum scores Knowledge T1" and "Sum scores Knowledge T3". The resultant Comparative Fit Index (*CFI*) of 0.954 and Tucker-Lewis Index (*TLI*) of 0.939 are deemed acceptable, given that the Root Mean Square Error of Approximation (*RMSEA*) is <0.050 ($p=0.042$), indicating a favorable fit to the model. Additionally, a Standardized Root Mean Square Residual (*SRMR*) of 0.044 further signifies a satisfactory fit. However, the Chi-square statistic ($\chi^2=85.248$, $df=50$, $p=0.0014$) suggests a one-in-a-thousand occurrence, implying that the data does not entirely align with the model (Phakiti, 2018). The resulting structural equation model (see Fig. 1) illustrates that the observed variables almost equally contribute to characterizing the latent variables "*act*" and "*flow*," as evident from their respective factor loadings. Consequently, the abbreviated scale appears largely suitable, albeit potential refinement for enhanced reliability may be warranted as a measuring instrument among eighth-grade students (see Fig. 1). All factor loadings, except for the items "While working on something I enjoy, the work feels automatic and effortless" and "I looked at a problem or task from a different angle to find a solution," which were constrained at 1.000 and not estimated, demonstrate significance at $p\leq 0.001$.

Gender Differences

The Act scores were, on average, 0.06 higher among female participants (95%-CI [-0.40, 0.01]), and the Flow scores were also 0.20 higher compared to male participants (95%-CI

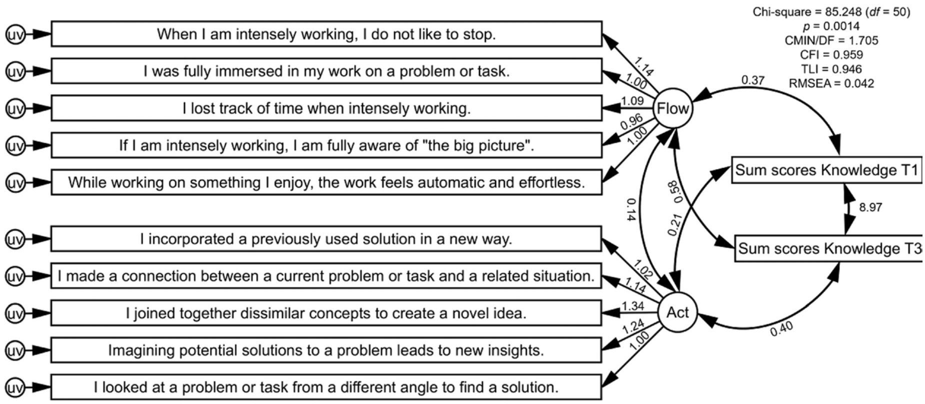

Fig. 1 Confirmatory factor analyses of the Cognitive Processes Associated with Creativity Scale with model fit indices (*CMIN/DF*=Chi-Square divided by the degrees of freedom, *CFI*=Comparative Fit Index, *TLI*=Tucker-Lewis Index, *RMSEA*=Root Mean Square Error of Approximation)

Table 2 Pearson correlations (*r*) of the Creativity Scale's latent factors act and flow with gender

	Subsamples			Mean scores		t-Test		
	N (male)	*N (female)*	*N (divers)*	*M (male)*	*M (female)*	*T*	*df*	*p*
Act	159	226	8	-0.04	0.01	-0.548	383	0.584
Flow	159	226	8	-0.11	0.08	-1.912	383	0.057

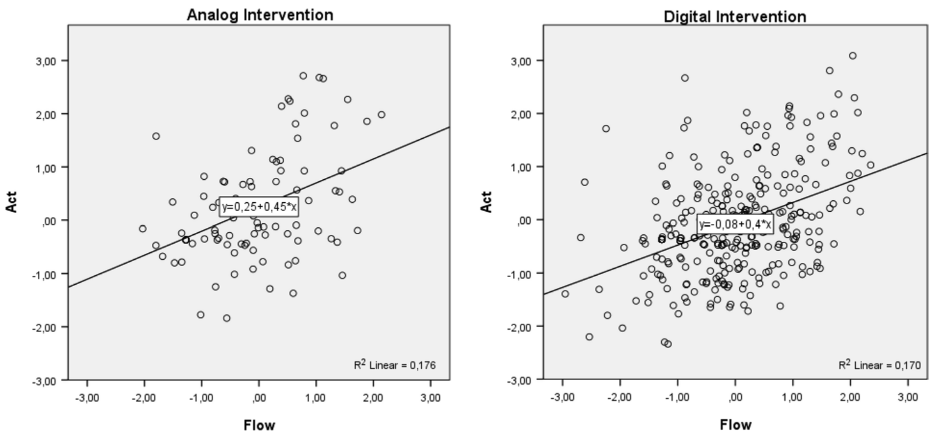

Fig. 2 Regression of the factors „Act" and „Flow" in the analog and digital subsample

[-0.26, 0.15]). However, there was no statistically significant difference between the Act and Flow scores of male and female participants as shown in Table 2. The students who identified as diverse in the survey were not included in the calculations. The lack of differences between genders suggests that gender might not have an influence on a person's creativity and thus, on the manifestations of the subscales act and flow.

Table 3 Pearson correlations (*r*) of the Creativity Scale's latent factors act and flow with knowledge sum scores of the different testing points T1, T2 and T3 (Mean scores Analog: T1 = 14.20, T2 = 16.14, T3 = 15.88; Mean scores Digital: T1 = 14.80, T2 = 16.68, T3 = 15.85) of the analog and digital intervention. Note: *ns = not significant*

	Knowledge T1	Knowledge T2	Knowledge T3
Analog Intervention			
Act	*ns*	*ns*	*ns*
Flow	$r=0238$ $p=0.021$* $N=93$	$r=0.275$ $p=0.018$* $N=74$	$r=0.347$ $p<0.001$*** $N=93$
Digital Intervention			
Act	$r=0.143$ $p=0.013$* $N=300$	$r=0.182$ $p=0.006$** $N=231$	$r=0.158$ $p=0.006$** $N=300$
Flow	$r=0.177$ $p=0.002$** $N=300$	$r=0.200$ $p=0.002$** $N=231$	$r=0.212$ $p<0.001$*** $N=300$

Note: ns = not significant

Digital vs. Analog Intervention

Before the correlation analysis, we conducted a t-test with bootstrapping (using a bootstrapping procedure with 1000 repetitions and bias-corrected and accelerated [BCa] 95% confidence intervals [CIs]) to validate the comparability of the two subsamples (digital and analog) on the knowledge pre-test. On average, participants of the digital intervention scored slightly higher on the knowledge pre-test ($M=14.80$, $SE=3.49$), than those of the analog intervention ($M=14.20$, $SE=3.74$). This difference of -0.60 points, with a BCa 95% confidence interval ranging from −1.53 to 0.17, was not statistically significant ($t(391)=-1.42$, $p=0.156$). Since this analysis did not reveal any significant differences and the variances appeared similar, we are confident in using this data for the further correlation analyses.

Significant differences emerge between the digital and analog instructional groups regarding the correlations between knowledge scores at different time points and cognitive factors (Table 3). First, in the digital group, the knowledge level at T3 exhibits a stronger positive correlation with T1 ($r=0.600$, $p<0.001$) compared to the analog group ($r=0.485$,

Table 4 Pearson correlations of the cognitive factors „Act" and „Flow" with knowledge differences of pre- and post-test, and pre- and retention test in both subsamples and correlation comparison using Fisher's *z*

	Analog Group	Digital Group	Fisher's z (1925)
r (Act x Diff_T2-T1)	0.067	0.083	$z=-0.1184$, $p=0.906$
p (Act x Diff_T2-T1)	0.855	0.069	
N	74	231	
r (Flow x Diff_T2-T1)	0.028	0.121	$z=-0.6886$, $p=0.491$
p (Flow x Diff_T2-T1)	0.815	0.066	
N	74	231	
r (Act x Diff_T3-T1)	0.164	0.058	$z=0.8928$, $p=0.372$
p (Act x Diff_T3-T1)	0.117	0.321	
N	93	300	
r (Flow x Diff_T3-T1)	0.142	0.092	$z=0.4214$, $p=0.673$
p (Flow x Diff_T3-T1)	0.174	0.113	
N	93	300	

r = Pearson correlation coefficient, p = statistical significance of the correlation coefficient, N = sample size

$p < 0.001$). This suggests that students' initial knowledge (T1) is more strongly associated with their retained knowledge after the learning module (T3) in the digital group. Second, significant correlations between knowledge at all testing points and the cognitive factor "Act" are evident in the digital group, whereas no such relationships exist in the analog group. Third, in the digital group, the "Flow" factor correlates highly significantly with all knowledge testing points, whereas in the analog group, correlations between "Flow" and T1 or T2 are only significant. "Flow" is therefore crucial in both groups but is particularly noticeable at the digital group.

Despite these differences, commonalities are observed in both groups. There are highly significant positive correlations between knowledge levels at different time points (T1 x T2: $r_{analog} = 0.545$, $r_{digital} = 0.527$; T1 x T3: $r_{analog} = 0.485$, $r_{digital} = 0.600$; T2 x T3: $r_{analog} = 0.545$, $r_{digital} = 0.692$). The correlation between T1 and T2 is similar for both groups suggesting that both analog and digital methods are effective in enhancing immediate knowledge acquisition. However, the digital group shows a stronger correlation between T2 and T3 compared to the analog group, indicating better retention of the acquired knowledge in the digital group. Therefore, while both analog and digital learning methods are effective in increasing knowledge immediately after the intervention, digital learning methods may provide better long-term retention. Furthermore, highly significant positive correlations between the cognitive factors "Act" and "Flow" are evident in both groups (Act x Flow: $r_{analog} = 0.420$, $r_{digital} = 0.412$, $p < 0.001$; Fig. 2). However, there are no significant differences between the digital and analog subsamples (Fisher's $z = 0.0804$, $p = 0.936$).

During the correlation analysis of the cognitive factors "Act" and "Flow" with the knowledge differences between pre- and retention tests, no significant correlations were observed within the subsamples, and no significant differences were identified between the correlations of the groups (Table 4).

Discussion

Usage of the Abbreviated CPAC Scale

In discussing the suitability of the shortened Cognitive Processes Associated with Creativity (CPAC) questionnaire for 8th-grade students, it is crucial to consider the implications of the findings regarding its generalizability and psychometric properties within this specific demographic. Notably, the successful application of the shortened CPAC questionnaire by Conradty & Bogner (2019) with German tenth graders at Bavarian high schools and by Conradty & Bogner (2019) with European participants aged 11–19 years highlights its versatility across different age groups. Furthermore, in alignment with the approach taken by Conradty & Bogner (2019) in their study, we excluded the item "I asked other people to help generate potential solutions to a problem," which may necessitate a modified phrasing in future research. Our findings support the assertion that the shortened CPAC questionnaire is suitable for use with 8th-grade students. However, further research is needed to establish its construct validity for this specific age group. Additional studies could further explore its correlation with other measures of creativity in 8th graders. In conclusion, the results suggest that the shortened CPAC questionnaire exhibits promise for widespread applicability across various grade levels and educational contexts. For future investigations, further exploration of its validity and potential for adaptation to different age groups may be warranted to enhance its efficacy as a research instrument.

Gender Aspects

Building on the investigation into the suitability of the shortened CPAC questionnaire for 8th-grade students, the next research question to consider is: Are there gender-specific differences in creativity and its association with learning outcomes? This question delves into the potential variability in creative thinking abilities between male and female students and examines how these differences may impact their educational achievements. By exploring the interplay between gender, creativity, and academic performance, we aim to gain a deeper understanding of how these factors interact within the context of 8th-grade education. Our study did not identify any significant gender differences in creative thinking or its association with learning outcomes among 8th-grade students, which aligns with recent research trends (e.g. Roth et al., 2022b). In the study by Roth and colleagues (2022a), gender differences were observed only in the upper and lower age ranges of 10th graders. This led them to conclude that promoting individual creative endeavors might hold the solution. Already in 1996, Csikszentmihalyi postulated that it is not gender but rather a traditional gender-specific upbringing of boys and girls that determines their development. This cultural discrimination could be an explanation for the disparate results of previous international studies on gender differences in creativity (Conradty & Bogner, 2018). According to recent findings from the TIMSS study in 2019, however, this gender gap appears to be steadily decreasing (Mullis et al., 2020) - which would quite align with our results. This highlights the need for further research by comparing countries and age groups in conjunction with collecting sociocultural data to explore these nuances that might influence creativity development. Our findings suggest that focusing on individual student needs may be more productive than relying on potential stereotypical gender categories in educational practices.

Impact of Flow, Creativity, and Game-Based Learning on Learning Success

Our findings again highlight the potential of creativity to support individual learning success. We observed correlations of the cognitive factors „Act“ and „Flow“ with knowledge sum scores and knowledge differences (Tables 3 and 4). It therefore clearly appears that the more creative an individual is and consequently, the more pronounced their experience of “Act” and “Flow”, the higher their learning success tends to score. These results align with previous studies (Conradty & Bogner, 2018; Mierdel & Bogner, 2019; Roth et al., 2022a). Flow experiences are considered crucial for developing creativity, as they are typically accompanied by positive emotions (Csíkszentmihályi, 2000). However, creating an environment conducive to flow requires special conditions, wherein the difficulty of tasks is balanced between challenging and accessible for students (Roth et al., 2022b). However, the perceived task difficulty varies from person to person. Since students frequently become fully absorbed in their tasks, a sense of complete security is another essential requirement for experiencing flow, which is also significant (Conradty & Bogner, 2018; Csikszentmihalyi, 1996). This sense of security can be achieved in open learning environments that facilitate a high degree of self-regulation, presenting teachers not as instructors following fixed lesson plans but as mentors (Roth et al., 2022b). In their new role as mentors, teachers can contribute to students' sense of security while encouraging them to explore individual learning and problem-solving approaches (Csikszentmihalyi, 1996). This can enhance motivation (Conradty & Bogner, 2016), creativity (Conradty & Bogner, 2018), and even learning success (Thuneberg et al., 2018). The more frequently learners experience flow, the stronger their self-efficacy becomes, further impacting motivation, persistence, and likelihood of success (Conradty & Bogner, 2024). In contrast, excessive rules and external incentives, such as exams or time pressure, hinder creative actions (Csíkszentmihályi, 1975).

Although in our study we were able to ensure some of those essential factors, such as a more open and ungraded learning environment, it was challenging to entirely eliminate inhibitory factors, such as time pressure and specific rules inherent to the school framework. Even though students were informed that their work wouldn't be graded, the presence of regular teachers during the interventions might have created an implicit testing situation. Furthermore, the prospect of reward, not uncommon in analog Edu Breakouts (contents of the treasure chest), could have negatively impact the participants' creativity by potentially undermining their intrinsic motivation (Ryan & Deci, 2009). Participants of the digital intervention were not informed about the reward at the end of the intervention. This could be a possible explanation for the highly significant correlations between "Flow" and "Knowledge" measured at all test points in the digital group, while they were only significant in the analog group. A further explanation might be that students in the digital intervention could work alone at their own pace if they chose to, without being constantly interrupted by others during their learning flow. Liao (2006) found that student interactions did not correlate positively with flow experience, while the interaction between learners and instructors and between learners and the user interface showed positive correlations.

Flow and emotional engagement are known to significantly impact motivation, which in turn positively impacts academic success in a gamified online learning environment (Özhan & Kocadere, 2020). Similar findings were reported by Hsieh and colleagues (2016), who found that higher flow experiences in game-based learning were associated with higher learning performances in elementary school students. As both of our gamified learning modules lead to significant learning success, with flow positively correlating with students' learning success, we concur with these studies. Additionally, inquiry-based tasks, as implemented in our learning modules, can promote cognitive flexibility, support the development of creativity in students (DeHaan, 2011), and enhance students' learning success (Lazonder & Harmsen, 2016). Modern education, allowing autonomy and the free choice of learning paths in open educational environments has the potential to further promote creativity.

To further develop educational policies and practices, our findings therefore suggest and confirm that creativity should be strengthened in classroom teaching, particularly in science education. Some prominent key approaches to implementing creativity are: (1) Project-based learning that engages students in meaningful real-world projects making learning more creative and relevant for students (e.g. Hanif et al., 2019). (2) Critical thinking and problem-solving that empower students to analyze complex issues, evaluate multiple perspectives, and develop innovative solutions while deepening their understanding of subject matter (e.g. Birgili, 2015). (3) Hands-on experimentation in creative open inquiry settings that involves students actively participating in the scientific process of knowledge gain (e.g. Havu-Nuutinen et al., 2017). (4) Gamification and game-based learning with a course of play that paves the way for students to experience flow and self-directed action (e.g. Barata et al., 2013; Kalogiannakis et al., 2021). (5) Emphasis on the role of the teacher as mentor and moderator, without ignoring that students also need guidance (e.g. Davies et al., 2014; Martins Gomes & McCauley, 2021).

Differences Between Digital and Analog Learning

Ultimately, this study aimed to investigate the extent to which creativity and the associated cognitive factors "Act" and "Flow" influenced learning success in digital and analog learning environments. As we tested creativity along with the knowledge pre-test, we regarded creativity as a kind of personality trait and did not intend to develop or change its extent. The correlation analysis revealed no significant differences in initial creativity levels between the digital and analog groups, suggesting comparable starting points regarding this factor. Still, we observed significant differences between the digital and analog instructional groups regarding the correlations between knowledge scores at different time points and cognitive factors "Act" and "Flow". In the digital subsample, "Act" exhibited positive correlations with all knowledge testing points, while no such correlations were found in the analog subsample. It appears that a strong manifestation of "Act" among students in the analog group may not have significantly impacted their knowledge acquisition on the taught topic, whereas students with a strong manifestation of "Act" from the digital intervention seem to benefit slightly more. A possible explanation for this observation could be the unfamiliar nature of the activities in the analog intervention, resulting in their learning capacities being distributed and their focus being divided between the implementation of actions and knowledge acquisition. Conversely the digital learning environment utilized activities likely more familiar to the students as "digital natives". Therefore, the factor "Act" may have contributed more to knowledge gain in this group. When examining the correlations of learning success with "Flow," a different picture emerged. It is noticeable that in our study, the learning outcome seems more strongly associated with a student's ability to achieve the "Flow" state than with the creativity factor "Act". A strong manifestation of "Flow" consistently correlated significantly with knowledge scores in both groups, particularly for the retention test. A potential explanation might be that "Flow" and emotional engagement significantly impact motivation, which in turn positively impacts academic success as Özhan and Kocadere (2020) found in their study evaluating a gamified online learning environment. However, our results (Table 4) indicate that, regardless of the learning environment (digital or analog), in this study, no correlation was found between the creativity factors "Act" and "Flow" and the knowledge gains. It is possible that other, unmeasured factors may play a larger role in knowledge acquisition. Future research could explore these additional factors to gain a more comprehensive understanding of how learning environments influence knowledge gain.

Study Limitations

The generalizability of our findings is limited by the specific participant pool and by the application within COVID-time frame. Our study exclusively included eighth-grade students from the highest secondary school achievement level ("Gymnasium") in Germany. The results may not be applicable to students from other types of schools, grade levels, or educational systems. Additionally, the uneven sample sizes between the analog ($n=93$) and digital ($n=300$) subsamples introduce potential biases and limit the generalizability of comparisons between the two learning environments. Despite these limitations, our study offers valuable insights into the relationship between creativity, learning success, and flow experiences in an educational context. Future research could address these limitations (for instance its stimulus for educational policies) and further explore the interplay between creativity, learning environments (digital vs. analog), and learning outcomes, as well as gender differences. Examining the influence of additional factors, such as student motivation, learning styles, and teacher characteristics, on the relationship between creativity, flow, and learning success could also provide a more comprehensive understanding. By addressing these limitations and pursuing further research avenues, we can gain a deeper understanding of how to foster creativity and promote effective learning in both digital and analog educational settings.

Conclusion

Our findings suggest creativity as one acting force for learning success, regardless of the specific instructional method (digital or analog) employed. However, for creativity to flourish, learning environments needs specific design to facilitate the development of “Act” and “Flow” experiences among students. This precondition aligns with research suggesting that student autonomy and self-directed learning can enhance motivation and knowledge acquisition. Teachers can play a crucial role in fostering these conditions by transitioning from the role of instructor to that of a mentor, providing support and guidance when needed while allowing students greater ownership of their learning journeys. By minimizing external pressure, teachers can create space for students to achieve a state of “Flow,” which has been shown to positively intervene with learning outcomes.

Our study also suggests that gender-specific differences in creativity may be diminishing, supporting the notion of individualized instruction that caters to students’ unique needs and learning styles. Moving away from rigid, one-size-fits-all instructional approaches and embracing student autonomy can empower them to find their own learning paths. Playful learning environments, such as those incorporated in Edu Breakouts, can further enhance motivation and promote the development of interdisciplinary skills and creativity. Therefore, we encourage educators to explore gamified learning approaches as a potential tool to prepare students for the challenges of the 21st century by fostering creativity, critical thinking and mental flexibility.

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Declarations

Conflict of Interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no competing interests to declare that are relevant to the content of this article. Neither are there any financial or proprietary interests in any material discussed in this article and declare that they have no conflict of interest.

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