Research in Science Education (2022) 52:1293–1312
https://doi.org/10.1007/s11165-021-10005-x

Testing Creativity and Personality to Explore Creative Potentials in the Science Classroom

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Accepted: 12 April 2021 / Published online: 28 May 2021

Abstract

Integrating creativity into science classes may pave the way to tapping complex scientific phenomena. Although not yet conclusively defined nor assessed using standardized measures, creativity is understood to support cognitive learning in formal and informal settings. However, the successful integration of creativity in educational modules depends on many factors. As our knowledge of how to identify these factors is still limited, teachers may have difficulties effectively monitoring and fostering creativity. Consequently, a valid means to measure creativity would help teachers to identify creativity and its influencing factors within the limited scope of science lessons. In the present study, we collected data from 538 Bavarian secondary school students ($M \pm SD = 16.96 \pm 2.99$; 65.4%, female) focussing on personality and creativity measures. Comparable to previous studies, two subscales for creativity were applied: *act*, comprising conscious and adaptable cognitive processes, and *flow*, describing a creative mental state of full immersion. Since personality is understood to be linked to creativity, we used the *Big Five* scale with its shortened item battery to assess personality. We found that personal characteristics such as *conscientiousness* and *flow*, *openness* and *agreeableness*, and *extraversion* and *neuroticism* were significantly correlated. Anticipated gender and age differences were only evident when extreme groups were compared: *age* influenced *act* in younger male students and *flow* in older female students. Drawing on the literature and our results, we suggest pedagogical approaches to provide opportunities for creativity in science classrooms.

Keywords Creativity · Personality · Science education · CPAC · BFI-10 · Gender · Age

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Introduction

The task of fostering creativity – along with other, related personality traits – is increasingly gaining attention in educational settings as a result of the Ministry of Education's focus on competence development (KMK, 2020). Creativity is understood to support the acquisition, transfer, and application of knowledge in schools and, hence, to contribute to an innovative and flourishing national economy (Lewis, 2008). Integrating creativity into science education thus promises a more sustainable approach to the provision and management of knowledge (Henriksen et al., 2018). However, authors such as Wyse and Ferrari (2015) have so far recommended that the integration of creativity should occur, primarily, in arts-related subjects. This excludes many other relevant subjects – for instance, science classes – which lack representation in training plans (Robinson, 2011). Yet, creativity is a critical aspect of science education, with factual knowledge alone no longer sufficient to foster the development of know-how and new scientific concepts (Brynjolfsson & McAfee, 2014). On the contrary, it is increasingly evident that the self-perpetuating system of "linearity, conformity, and standardization" does not advance "organic, adaptable, and diverse" societies (Robinson, 2011, p.4).

To quantitatively measure creativity in educational contexts, we applied the empirical tool *Cognitive Processes Associated with Creativity* (CPAC, Miller & Dumford, 2016) which has been significantly shortened by Conradty and Bogner (2018) who were, subsequently, the first to apply the tool in informal science learning modules (Conradty & Bogner, 2019). The empirical focus was primarily on the subscales *act* and *flow* (Conradty & Bogner 2018; Conradty & Bogner 2019). As creativity is understood to be specific to individuals and linked to personality factors (Kaufman et al., 2008; Barron & Harrington, 1981), we used the *Big Five* scale (Caprara et al., 1993) in its shortened version *BFI-10* (Rammstedt & John, 2007) to explore previously reported interconnections with personality. Based on existing literature and our results, we suggest pedagogical approaches that create opportunities for creativity in science classrooms.

Theoretical Background

Attempts to define creativity have earned it a reputation as a particularly elusive construct (Corazza, 2016; Plucker and Renzulli 1999). Torrance (1988) suggested that "creativity defies a precise definition because it is largely unseen, nonverbal, and unconscious" (p. 43). As no standard definition exists, different elements related to individual perceptions of creativity are often added and later dismissed (Runco, 2019) in accord with individual perceptions of creativity. Runco and Jaeger (2012), for instance, first focused on "originality" and "effectiveness" as integral elements of the creative product but later reconsidered their decision and instead emphasized the less static creative process. For the present study, the definition of creativity for educational context proposed by Henriksen et al. (2018) seems to be most fitting: creativity is both "novel and effective, in addition to the subtler component of wholeness or context […] which exists as a dynamic process emerging through a system of interactions" (p. 29).

Csikszentmihalyi (1988), for instance, extended the discourse around creativity beyond a mere definition with the claim that creativity is the outcome of three integral driving elements: social institutions (the environment that determines what is considered creative), a stable cultural domain (the social structures that help preserve and pass on what is creative), and the individual's innovative capabilities (the creative actions that may change the domain or environment). While, coincidentally, observing artists at work, Csikszentmihalyi also recognized how immersed they were in the process and how this influenced their creative power (Cseh, 2016). The word *flow* may best describe this state and has, thereby, become a key element of motivation and creativity studies (Piniel & Albert, 2020) and of relevance to the study reported here.

Creativity's Contemporary Relevance

The perceived importance of research into creativity reflects the increasing recognition of the need to support creative thinking in a competency-focused and innovative society (Corazza, 2016). On a daily basis, people are exposed to a flood of information, and efficiently transforming this information into know-how requires creativity (Chua, 2015). Perry-Smith (2014) designed a creativity-supporting environment that could also be transferred to science education settings. She proposed that individuals must be exposed to a variety of different frames – defined as "lenses through which individuals view a situation or problem, [or] a way for individuals to make sense of a problem" (Perry-Smith, 2014, p. 833) – to broaden their interpretative horizon. This exposure to different frames relies on meaningful social interaction and communication: both are key to promoting the type of diverse and resourceful working atmosphere which, by offering various frames, can nurture creativity. In return, creativity may foster innovation, which is important from an economic and social perspective (Perry-Smith, 2014). Innovation involves the development of effective, novel solutions to problems and, thus, entails creative problem-solving strategies. These strategies are particularly important in the fields of science and mathematics, meaning this form of expressed creativity is highly relevant for both science professions and science education (Aldous, 2007).

Creativity in Science Education

Current educational policies and attempts to standardize school systems tend to reduce creativity rather than to promote it (Kupers et al., 2018). Therefore, teachers have to find ways to encourage creativity, particularly in science classrooms, so that graduates can meet the demands of an innovative, globalized economy (Henriksen et al., 2018) and develop creative approaches to problems ranging in complexity (Aldous, 2007). Of course, creativity is crucial to areas beyond the sciences (Lucas, 2016), but, due to the scope of this paper, we focus mainly on the role of creativity in this discipline. Currently, few students associate creativity with science or see scientific knowledge as the product of creative processes, even though "creativity is inextricably linked to the nature of science itself" (Hadzigeorgiou et al., 2012). The integration of creativity in science education "should be rooted in and reflect aspects of creativity seen in scientific research", and educators should "devise a framework appropriate to children's needs and abilities" that allows for creative processes (Kind & Kind, 2007, p.3). In this approach to science education, students still acquire scientific knowledge, but do not generate new knowledge themselves. Hence in trying to stimulate scientific creativity in the classroom, the teacher must acknowledge the differences between the learner role of the student and the creativity required of professional scientists (Hodson, 1998; Kind & Kind, 2007). Richards and Cotterall (2016) offer guidelines to help teachers establish creativity in class. While collaborative learning approaches require various teaching techniques (Yager,

2005) and effective teacher training to sustain creative processes in the science classroom (Goodwin & Gotlib, 2004; Sawyer, 2012), some researchers suggest that enforced group work may diminish creative thinking (Csikszentmihalyi, 2000; Schmidt, 2011). Most importantly, extrinsic motivators – for example, the evaluation of current work, offers of specific rewards Lepper and Greene 1978, or situations that could be interpreted as relevant for exams – should be avoided. Although these are common school practices, they can have a detrimental effect on creative processes (Baer, 2010; Amabile, 1983). The specific rewards, in particular, may bear "hidden costs" for the development of creativity since they undermine intrinsic motivation (Baer, 2010, p.25).

Gender in Creative Science Education

Creative thinking in science subjects also appears to be influenced by gender. Okere and Ndeke (2012) identified considerable gender-related differences in scientific creativity in terms of flexibility, planning, and recognition of relations. Other researchers, however, have not found any significant gender-related differences regarding general creativity (Charyton & Snelbecker, 2007; Charyton et al., 2011). A possible reason for these diverging results could be male and female interest and performance in scientific subjects rather than in creativity itself. Trends in International Mathematics and Science Studies (TIMSS), which measure the basic understanding of maths and science, support this theory since historically, male students have generally outperformed females in most science disciplines and expressed more interest in scientific topics (Neuschmidt et al., 2008; Goldman & Penner, 2016; Mejía-Rodríguez et al., 2020). Yet, in the most recent TIMSS 2019 report, they also found that girls may outperform boys in experiments where specific procedural steps were not included in the directions and many other scientific domains that involve reasoning and the application of knowledge (Mullis et al., 2020). If current understandings are correct that creativity is linked to intrinsic motivation (Csikszentmihalyi, 2000; Baer, 2010; Runco, 2014), genuine interest in the respective subject area may also indirectly influence scientific creative thinking and creative processes. Recent TIMSS reports (Mullis et al. 2020) also show that the gender gap is steadily decreasing (Neuschmidt et al., 2008; Mejía-Rodríguez et al., 2020), suggesting that the identified gender differences in creativity can be attributed to group effects (Baer, 2010; Charyton et al., 2011).

Establishing Creative Science Classrooms

Sawyer (2012) expects that collaborative learning approaches, in particular, will further contribute to gender balance in science subjects and thus in scientific creativity. The framework developed by Kaufman et al. (2008) for categorizing the development of an individual's creativity supports this assertion. Kaufman et al. divided creativity into four categories: (1) mini-c, which encompasses early and exploratory approaches to uncover individual creativity; (2) little-c, which develops with encouragement and several trials of mini-c creative processes; (3) pro-c, wherein the individual is "capable of working on problems, projects, and ideas that affect the field as a whole"; (4) and big-C, which is accomplished after many years of creative practice and is referred to as "eminent creativity" (Kaufman & Beghetto, 2009, p.6). Social interactions in the classroom may foster little-c creativity as classmates and teachers challenge creative scientific contributions made by individuals. This, in turn, can encourage mini-c creative thinking as individuals reflect on their own creative scientific interpretations.

However, the degree of structural freedom necessary to effectively foster creativity would require schools to fundamentally rethink classroom teaching (Cho et al. 2017). Since student learning in school science lessons is characterized by trial and error approaches and a lack of profound factual knowledge, teachers should create learning environments wherein extrinsic motivators are considerably reduced and which offer students the freedom to creatively explore scientific learning content individually or in groups to find an adequate solution to a scientific problem (Lepper & Greene, 1978). The structural freedom and open classroom may accordingly enable creative thinking both collectively and individually dependent on individual preferences (Amabile & Pratt, 2016; Beghetto, 2015). Yet, this necessary classroom transformation would require extensive teacher training and substantial investments beyond the capacity of many schools (Cho et al. 2017).

Measuring Creativity in Science Classrooms

Another major obstacle to promoting creativity in science education is the difficulty in measuring creativity and the resulting best practices for teaching. Although Hocevar and Bachelor (1989) identified over 100 applied measures, all followed different approaches. Piffer (2012) attributed this phenomenon to the lack of a standard definition of creativity, yet all measuring techniques were based on the four main categories of creativity – “process, product, person, and press” – each with a different focus on one category (Said-Metwaly et al., 2017, p.243). Accordingly, when selecting suitable measuring techniques, it is important to remember that, while there is no consensus on a single definition, there can be no single, authoritative measure for creativity.

At best, common creativity tests can grasp “aspects of [individual] creative potential” (Piffer, 2012 p.263). This, along with an often unnecessarily long test design, discourages teachers from identifying and fostering creative skills in the classroom. Thus, effectively integrating creativity into the science curriculum would require rapid testing and conclusive results (Kaufman et al., 2008). Teachers would also require sufficient tools to (1) understand test results, (2) draw links between the results and beneficial changes in science teaching and classroom setup, and (3) implement the findings in a way that effectively fosters creativity (Horng et al., 2005). That is, measuring changes in students’ creativity and reading how to nurture this creativity help teachers to redesign their lessons, adapt the classroom environment to their students’ various needs, and, finally, encourage individual scientific creativity (Südkamp et al., 2012; Gralewski & Karwowski, 2019).

Applied Empirical Instruments

Since creativity is understood to be linked to personality (Kaufman et al., 2008; Barron & Harrington, 1981), we decided to combine the shortened version of Miller’s (2014) Cognitive Processes Associated with Creativity (CPAC) scale, which also best reflects the different dimensions of Henriksen et al.’s (2018) definition of creativity, with the *Big Five* questionnaire (Caprara 1993) in its ten-item version, commonly referred to as *BFI-10* (Rammstedt & John, 2007), to explore students’ creativity and their individual personality factors related to creative activities (Kaufman et al., 2008). In this context, we also show that each of the 25 items has already been successfully implemented in different science classroom settings. For teachers, this combination would, thus, provide two measuring techniques to reliably assess aspects of creative potential and personality (Conradty & Bogner, 2018; Conradty & Bogner, 2019).

The CPAC scale has proven particularly suitable for assessing six dimensions of creativity – "idea manipulation, idea generation, flow, imagery/sensory perception, incubation, and metaphorical/analogical thinking" – using a set of 28 items (Tsai, 2018, p.271). Since the use of a scale comprising 28 items would take more time than is likely to be available for conducting such tests in science classrooms, a shortened scale was suggested by Conradty and Bogner (2018), involving only 15 items. Although shorter than the original developed by Miller (2014), this revised scale contains all relevant dimensions of the longer variant and has already been validated in science outreach education (Mierdel & Bogner, 2019).

Previous studies have already revealed generalizable correlations between the positive personality traits of *extraversion* and *openness* and creativity (Furnham et al., 2013; Antinori et al., 2017; Hoseinifar et al., 2011). *Openness* has recently been revealed to affect both how curiously and creatively individuals explore the world and how they actually experience and perceive their environment from a neurocognitive point of view. Yet, this trait is still among the least well understood of all five (Antinori et al., 2017). However, it is not only personality factors regarded as positive that are correlated with creativity but also *neuroticism* (Batey et al., 2010), with its subscales *volatility* and *withdrawal* (Watrin et al., 2019). *Neuroticism* refers to individual predispositions towards negative feelings such as anxiety, depression, and anger, as well as certain responses to loss or frustration. Expressions of *neuroticism* differ between genders (Tackett & Lahey, 2017), yet the trait is both positively and negatively related to many different measures of creativity. Other traits, meanwhile, are tied to specific aspects of creativity: *extraversion* is linked to creative achievement and *openness* to self-rated creativity (Batey et al., 2010). For a long time, personality was considered stable and unchangeable. However, recent studies, such as Kitamura et al. (2015), revealed that certain high-order personality traits included in the *Big Five* could change in response to various influences. This has inspired the idea of designing educational interventions specifically aimed at fostering behaviours directly connected to creativity (Hoseinifar et al., 2011).

Comparable to creativity, the feasibility of assessing personality has been widely discussed for decades, particularly with regard to the number of factors required in such assessments. One widely endorsed outcome was the *Big Five* questionnaire (Caprara 1993), although Eysenck (1981) had previously proposed the three-factor model *TFM* measuring *psychoticism*, *extraversion*, and *neuroticism*, based on biological theories. Eysenck also effected a shift to higher-order (type) factors to analyse personality, rather than of primary (trait) factors (Wiseman & Bogner, 2003). Caprara's (1993) questionnaire, however, has its roots in the assumption that certain personality and behavioural patterns are present in creative individuals (Barron & Harrington, 1981) and, accordingly, distinguishes between personalities regarded as "normal", "extremes of the normal", and "abnormal", for instance, obsessive-compulsive (Furnham et al., 2013). Thus, the questionnaire breaks down the complex construct of personality into five essential features – *neuroticism*, *friendliness* or *agreeableness*, *conscientiousness*, *extraversion*, and *openness/intellect* – originally comprising over 100 items in its standardized version (Watrin et al., 2019). Many researchers (Carciofo et al., 2016; Balgiu, 2018) today, however, deploy the *Big Five*'s shortened version with only 10 items, commonly referred to as *BFI-10.* The shortened scale is in no way inferior to the more detailed scale, especially in classroom settings, which has been proven by Rammstedt and John (2007), hence our decision to use the *BFI-10*.

Our study set out to answer three research questions. (i) How do the shortened versions of the *CPAC* and *Big Five* capture their respective constructs in classroom settings? (ii) How does personality – as described in the *BFI-10* – correlate with *act* and *flow* in the *CPAC* questionnaire? (iii) How do groups at either end of the age spectrum differ in gender-specific creativity and personality characteristics?

Materials and Methods

Sampling Procedure

Altogether, 538 Bavarian secondary school students from three schools with a focus on STEAM education participated in our study (girls 65.4%, boys 34.6%; $M_{Age} = 16.96$; $SD = 2.99$). They completed a questionnaire comprising 25 questions extracted from the *BFI-10* and *CPAC* scales during their biology classes. Regarding the construct validity of *CPAC*, inter-item correlations below 0.20 confirmed that each item referred to different creativity facets. Furthermore, the heterogeneity of the items with respect to complex constructs, such as creativity, emphasizes the given construct validity (Rost 2004). The *Big Five* consists of 10 items taken from the *BFI-44*, with two items for each *Big Five* domain (one reverse-scored): extraversion (items 6, 36); agreeableness (items 2, 22); conscientiousness (items 3, 23); neuroticism (items 9, 39); and openness (items 20, 41). Each item was assessed using a 5-point Likert scale ranging from “strongly disagree” (1) to “strongly agree” (5) (Rammstedt & John, 2007). The same Likert scale was used to assess the *CPAC* items. The *CPAC* comprised a total of 15 items representing the creativity domains of *idea manipulation* (7, 15), *imagery/sensory* (1, 10), *flow* (2, 3, 9, 13, 14), *metaphorical/analogical thinking* (5), and *idea generation* (4, 6, 8, 11, 12) extracted from the original *CPAC* scale (Conradty & Bogner, 2018; Conradty & Bogner, 2019). The age and gender variables were collected by asking participating students for their age and gender, which was later categorized as a nominal variable.

Statistical Analyses

Subsequent statistical analyses were conducted using RStudio Team (2020) and IBM SPSS Statistics 26.0. Our data were not normally distributed following assessment with the Shapiro-Wilk test ($p < 0.001$). Despite our large sample size, we also refrained from normalizing the data as would be recommended by Bortz and Schuster (2010), since – due to Likert scaling – our measured values have no clearly interpretable relative distances. Moreover, our sample is largely heterogeneous in terms of age and gender distribution, which further encourages non-parametric analysis (Lomax, 1986).

We used RStudio Team (2020) for confirmatory factor analysis of the shortened *CPAC* to show that the predicted structure from our previous interventions (Conradty & Bogner, 2018; Mierdel & Bogner, 2019) was replicable (Thompson, 2004). Based on theory (Kaiser, 1970) and previous analysis (Conradty & Bogner, 2018), we assumed our sample would divide into two factors *flow* and *act.* To confirm the model’s adequacy, we calculated the comparative fit index ($CFI = 0.837$) and Tucker-Lewis index ($TLI = 0.808$) as well as the root mean square error of approximation ($RMSEA < 0.050$, $p = 0.492$). We also extracted factor scores for further calculations and factor loadings for a pattern matrix. Using a principal component analysis with subsequent oblique rotation – which reduces the data's dimensionality while retaining its variation (Bro & Smilde, 2014) – we evaluated the *Big Five* test. In accordance with the Kaiser-Guttman criterion (Kaiser, 1970), it was divided into five factors with the Kaiser-Meyer-Olkin ($KMO = 0.54$, $\chi^2 = 484.1$) values being just about acceptable, indicating that conducting a factor analysis with our dataset was feasible.

To explore potential gender differences, particularly with regard to outlying group differences in age, we applied Mann-Whitney *U* (MWU) tests (Field, 2012). Before correlation analysis, however, we randomly selected 340 participants from the overall sample to avoid producing biased results due to differences in age and gender groups. In case of significant results, effect sizes *r* (Lipsey & Wilson, 2001) were calculated with small (> 0.1), medium (> 0.3), and large (> 0.5) effect sizes. The results were transferred from R to SPSS to create boxplots with sufficient graphic quality.

Results

Our results indicate that both *CPAC* and *BFI-10* measure expected constructs, although not all observed variables adequately describe the latent constructs *act* and *flow* in the shortened CPAC scale. Moreover, gender differences only appear for outlying age groups and are otherwise not significant. Cronbach's α scored 0.675 for *CPAC* proving the scale's reliability to be acceptable (Lienert & Raatz, 1998). A subsequent principal component analysis with oblique rotation confirmed two factors based on eigenvalues <1.0, accounting for 60.03% of the total variance. All items displayed in the pattern matrix (Table 1) reached a total KMO

Table 1 Principal component analysis with *CPAC* after oblique rotation (valid $N = 538$)

Pattern matrix[a]		Components factor analysis	
		1	2
CPAC 08	If I get stuck on a problem, I try to take a different perspective of the situation	.633	
CPAC 10	Imagining potential solutions to a problem leads to new insights	.589	
CPAC 07	Thinking about more than one idea at the same time can lead to a new understanding	.546	
CPAC 15	If I get stuck on a problem, I look for details that I normally would not notice	.403	
CPAC 04	While working on something, I try to generate as many ideas as possible	.419	
CPAC 01	Becoming physically involved in my work leads me to good solutions	.291	
CPAC 05	If I get stuck on a problem, I look for clues in my surroundings	.254	
CPAC 12	I get solutions to problems when my mind is relaxed	.254	.241
CPAC 6	When I get stuck on a problem, a solution just comes to me when I set it aside	.181	
CPAC 13	While working on something, I try to fully immerse myself in the experience		.650
CPAC 02	When I am intensely working, I do not like to stop		.534
CPAC 14	I can completely lose track of time if I am intensely working		.559
CPAC 03	If am intensely working, I am fully aware of "the big picture"		.289
CPAC 09	While working on something I enjoy, the work feels automatic and effortless	.221	.219

Extraction method: principal component analysis

Rotation method: Oblimin with Kaiser normalization

The rotation converged into 2 iterations score of 0.73 indicating reliable and distinct factors (Kaiser, 1970). Due to correlations between the components, however, we could calculate neither the sum of squared charges nor the total value.

We conducted a confirmatory factor analysis to confirm the shortened scale and its two main factors – *act* and *flow* – from preceding studies, for instance, Conradty and Bogner (2018). We also retained the previous renaming of the two factors originally introduced by Miller and Dumford (2016). The resulting $CFI = 0.837$ and $TLI = 0.808$ are permissible since the $RMSEA < 0.050$ ($p = 0.492$) is good and also accounts for model fit. Chi-square ($\chi^2 = 164.65$, $df = 89$, $p < 0.001$), however, indicates that the event occurs less than one time in a thousand and that data does not adequately fit the model (Phakiti, 2018). The resulting structural equation model (Fig. 1) indicates that some of the observed variables are better suited to describing the latent variables *act* and *flow* than other observed variables, as can be seen with respective factor loadings. Consequently, the short scale may need to be further modified to guarantee its reliability as a measuring instrument in science education (Fig. 1).

All factor loadings, apart from IG11 ($p = 0.209$) are significant with $p \leq 0.001$. Error variances of the observed variables are indicated in square brackets coloured in light grey. Since specific variance and error variance are analytically, inversely related, increased specific variance and reliability lead to decreased error variances (Lomax, 1986).

For *BFI-10*, we completed a principal component analysis with oblique rotation as recommended in the literature (Caprara 1993). This confirmed five factors based on eigenvalues <1.0. Due to correlations between the components, however, we could calculate neither the sum of squared charges nor the total value. Not all items as displayed in our pattern matrix showed loadings above the limit of 0.4 (Table 2) but still reached a total KMO value of 0.54, which barely indicates reliable and distinct factors (Kaiser, 1970) (Table 2). Bartlett's test

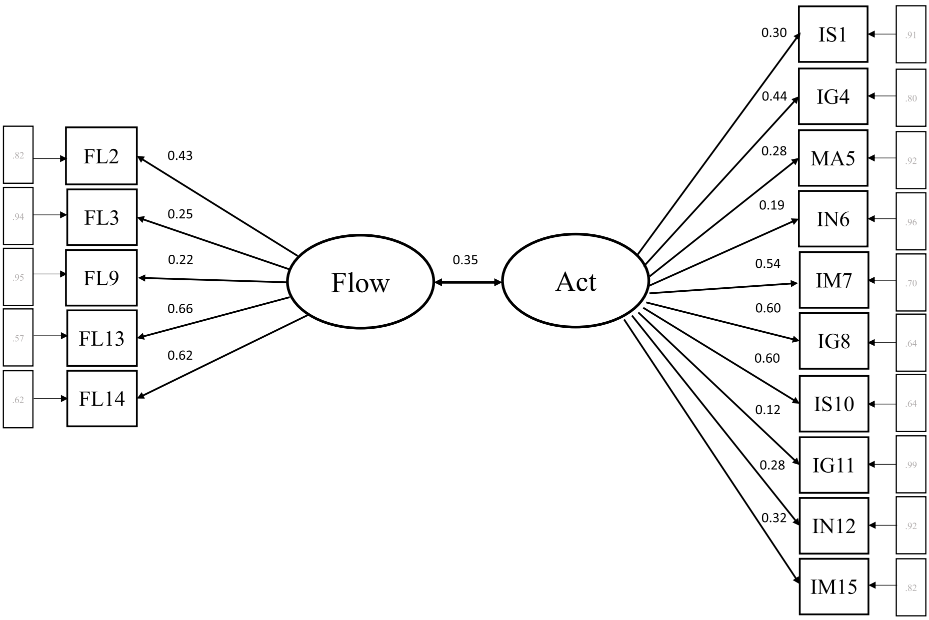

Fig. 1 Structural equation model of *CPAC* after confirmatory factor analysis with two factor structure *act* and *flow*

Table 2 Principal component analysis with *BFI-10* after oblique rotation (valid N = 538)

Pattern matrix[a]		Components factor analysis				
I see myself as someone who …		1 extraversion 1+6	2 conscientiousness 3+8	3 neuroticism 4+9	4 openness 5+10	5 friendliness 2+7
BF 6	… is outgoing, sociable	.961				
BF 1	… is reserved	.629				
BF 3	… tends to be lazy		.710			
BF 8	… does a thorough job		.685			
BF 4	… is relaxed, handles stress well			.512		
BF 9	… gets nervous easily			.785		
BF 10	… has an active imagination				.613	
BF 5	… has few artistic interests				.667	
BF 7	… tends to find fault with others					.653
BF 2	… is generally trusting					.324

Extraction method: principal component analysis

Rotation method: Oblimin with Kaiser normalization

Total eigenvalue explained 84,56%

Table 3 Mann-Whitney *U* test for gender effects after principal component analysis with *CPAC* and *BFI-10* ($N = 538$) for extreme groups regarding age

Age percentile	Mann-Whitney *U* test (MWU)	Act	Flow	Extraversion	Conscientiousness	Neuroticism	Openness	Friendliness
25	*r*	0.210	0.153	0.080	0.056	0.126	0.101	0.099
	Z	−2.456	−1.790	−.924	−.657	−1.369	−.237	−1.153
	p	.014*	.073	.356	.511	.171	.237	.249
75	*r*	0.089	0.199	0.027	0.164	0.063	0.094	0.079
	Z	−.932	−2.068	−.273	−1.704	−.652	−.974	−.729
	p	.351	.039*	.758	.088	.514	.330	.466

sphericity was $\chi^2 = 484.11$ ($df = 45$, $p < 0.001$). Thus, our data was just about suitable to replicate the five-factor structure of the *BFI-10* and confirm the model.

After principal component analysis with *CPAC* and *BFI-10*, we applied the *Mann-Whitney U* test to assess the effects of gender on creativity and personality characteristics in outlying age groups. We discovered significant gender differences for the latent factor *act* in the lower age percentile. There, young boys reach higher scores for action-based creativity as compared to that of the girls. However, our results yielded significant gender differences for the latent factor *flow* in the upper age percentile (Table 3), suggesting that older girls achieve higher scores for *flow* experiences. Effect sizes ranged from low to intermediate for all factors analysed with regard to gender differences (Lipsey & Wilson, 2001) (Table 3).

As is displayed in Fig. 2, the most significant differences between female and male students emerged in outlying age groups for *act* and *flow* after calculation of gender effects with factor scores. Here, young boys achieve higher scores than young girls for *act*, while older girls reach higher scores than older boys for *flow*. Accordingly, gender only appears to influence creativity in outlying age groups and, thus, may not be significant for classroom design. It may be far more important to restructure science classrooms to encourage individual creative actions (Fig. 2).

We attempted to calculate age-related effects for *BFI-10* using Kruskal-Wallis (Field, 2012). However, as the *Big Five* measures personality, which is regarded as stable, we could observe no immediate age-related effects (Watrin et al., 2019). Teachers should, therefore, not aim to influence the development of personality but try to provide learners with the freedom required to individually discover and enjoy their creative actions.

We also calculated correlations between *CPAC* and *BFI-10* factors using Spearman-Rho (Field, 2012). We obtained significant positive correlations ($p < 0.001$) between *conscientiousness* and *flow*, with a correlation coefficient of 0.115 but with low effect sizes. No further significant correlations could be obtained between the scales, but *flow* and *act* had significant positive correlations ($p < 0.001$) of 0.453 within their scale with a medium to large effect size. *Extraversion* and *neuroticism* displayed a highly significant negative correlation ($p < 0.001$) with a correlation coefficient of −0.558 with a large effect size (Lipsey & Wilson, 2001). This confirms the predicted connections between personality and creativity, showing that individual preferences are involved in creative action.

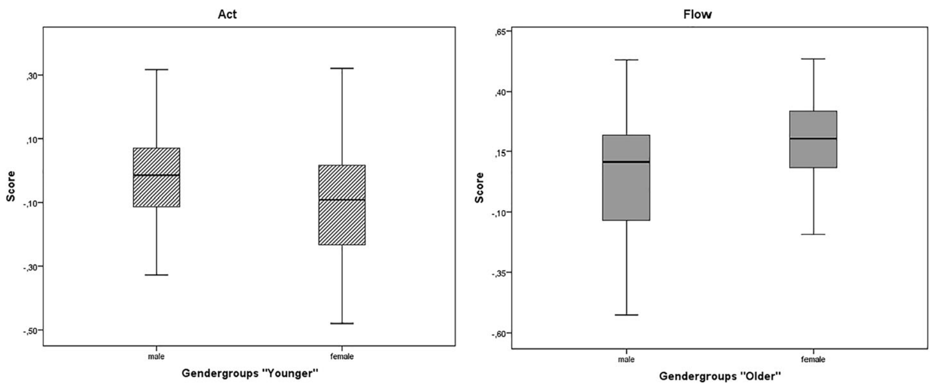

Fig. 2 Gender differences for *CPAC's* creativity dimensions *act* and *flow* dependent on age groups

Discussion

CPAC and Big Five Scale to Assess Creativity and Personality in Science Classrooms

CPAC to Assess Creativity in the Science Classroom We could confirm that the *Big Five* and *CPAC* scales in their shortened forms are both suitable for use in science classroom settings to assess personality and creativity, respectively. The shortened form of *CPAC* has already been used to help evaluate creativity across age groups and in different science teaching settings (Conradty & Bogner, 2018; Mierdel & Bogner, 2019). Our use of a confirmatory factor analysis to assess the shortened version of the test showed that some observable variables chosen from the original test are better suited to describing the latent construct than others. The variables FL3, MA5, IN6, FL9, and IN12 had particularly low factor loadings although they all produced significant descriptions of the latent construct. FL3 and IN6 were the weakest yet significant, observable variables. For FL9, significant cross-loadings additionally hamper a clear assignment to either *flow* or *act*. Without a clear reference, this observable variable could describe both constructs. IN6 is not a matter of assignment, yet may be misunderstood. That is, the solution to the problem could come while the individual subconsciously continues working on it, or the problem may be solved if the individual attempts to find a solution after a certain time has passed. This ambiguity may have led to lower factor loadings in describing *act*. We should, thus, consider whether other observable variables from the original scale could replace those with low factor loadings or if an even shorter version might be suitable for implementation.

In view of the other observable variables, however, the shortened version of the *CPAC* may be able to capture *act* and *flow* as aspects of creativity in science classrooms. The scale is, thereby, able to successfully measure the learning effect of creativity skills (*act*) and emotional factors that contribute to enjoyment in learning (*flow*). *Flow* experiences are believed to be crucial in the evolution of creativity as they are rewarded with positive feelings (Csikszentmihalyi, 2000). To enable *flow*, special environments are required wherein the difficulty of tasks is balanced between demanding and easy. The perceived difficulty of tasks, however, varies individually. Furthermore, as students often completely immerse themselves in their tasks, feeling absolutely secure is another basic requirement for *flow* to occur (Csikszentmihalyi, 2015; Conradty & Bogner, 2018). This level of security may be accomplished in open learning environments that enable a high degree of self-regulation, irrespective of fixed lesson plans for students, and present teachers not as instructors but as mentors. In their new role as mentors, teachers may add to the students' perception of safety while encouraging students to try out individual learning and problem-solving approaches (Csikszentmihalyi, 2015). This can promote motivation (Conradty & Bogner, 2016), creativity (Conradty & Bogner, 2018), and even learning success (Thuneberg et al., 2018). In contrast, many rules and extrinsic motivators, such as exams or time pressure, impair creative actions (Csikszentmihalyi, 1975). Since some rules are, however, mandatory in educational processes, educational settings that still include preparation, incubation, eureka effects, evaluation, and elaboration as the five contributors to creative processes may also be of use (Csikszentmihalyi, 1996).

BFI-10 to Assess Personality in the Science Classroom This kind of open learning environment also considers the needs of different personality types (Safwat et al., 2020), which could also influence creative actions (Kaufman et al., 2008). We measured personality using the *BFI-10* test, the short version of which is already established in most contexts, including science classrooms (Schumm, 2016; Carciofo et al., 2016). Yet, it is recommended that before using the scale, its feasibility should be assessed as, dependent on the culture, many variables can have different connotations and may, therefore, provide a distorted picture of personality distribution in the classroom (Carciofo et al., 2016). In our case, the *BFI-10* has proven to be effective for measuring personality across all age groups in science classrooms after assessment with principal component analysis. In addition to substantial factor loadings for all five latent variables (*extraversion*, *neuroticism*, *conscientiousness*, *friendliness*, *openness*), we have also been able to indicate the strong negative correlation between the latent variables *neuroticism* and *extraversion*, as has been suggested by the arousal model and the Yerkes-Dodson law (Aguilar-Alonso 1996).

Correlations between CPAC and BFI-10

Our results also show connections between the CPAC's latent variable *flow* and the personality trait *conscientiousness*. A study assessing the impact of *flow* experience on job performance received comparable results for *conscientiousness* (Chui & Lee, 2012), confirming general *flow* theory. When students are goal-oriented and hardworking, their *flow* experience will strongly impact their performance (Demerouti, 2006) as well as their commitment and motivation (Cacioppe, 2017). Essential for *flow* experience, however, is an open and flexible environment that offers opportunities for individual development. Therefore, *flow* has mainly been assessed in the context of activities such as dancing, reading, online communication, and art (Lian et al., 2018). Practising these, however, also requires commitment as is inherent to *conscientiousness* (Chui & Lee, 2012). In science education, *flow* can be best experienced within the scope of hands-on experiments, which optimally involve students while giving them full control of their actions. This freedom, however, also requires a high degree of conscientiousness (Hoseinifar et al., 2011). Extensive note-taking in instruction-heavy classroom settings is, in contrast, deemed detrimental to *flow* experience. The perceived time limit of science lessons also prevents students from fully immersing themselves in their tasks (Boyer & Lamoreaux, 1997).

Many of the skills relevant to dancing and art – such as posing high-level problems and questions, making decisions, or combining ideas in new ways – also play a major role in science education and may contribute to fostering creative actions (Yager, 2005). Maor and Jost (2017), for instance, effectively mixed art and mathematics by combining forms, patterns, and numbers in endless variations. This stimulates active reflection and the testing of solutions (Sawyer, 2012). Their educational goal to stimulate acts is supposed to encourage students to creatively interact with the difficult subject of mathematics by simply exploring, observing, explaining, and proving its different facets (Maor & Jost, 2017). A collaborative, stimulating, and interactive environment is thereby crucial to experiencing *flow* (Miller & Dumford, 2016; Csikszentmihalyi, 2015).

Gender Differences Regarding CPAC and BFI-10 at either End of the Age Spectrum

In our study, the most eminent gender differences emerged for *act* and *flow* with regard to outlying age groups. There, young boys of the lowest age percentile score higher for *act* than girls in the same age group. In terms of best practice for the science classroom, action-based exercises for the promotion of creativity in younger male children can be developed based on our findings. That is, group work encouraging the lively social and creative exchange of ideas and the freedom to actively reflect and try out solutions are both indispensable (Sawyer, 2012). Explorative and hands-on teaching with many experiments and opportunities to discover and think creatively are recommended.

As adolescence proceeds, *act*-related creativity differences between the genders balance out. Instead, differences in *flow* experience come into play. Young women in the upper age percentile seem to have a significantly better *flow* experience than their male counterparts. A key reason for this is might be socialization processes and cultural influences during adolescence (Iiamura & Taku 2018). That is, from an early age, societal influences may lead males and females to develop different ways of coping and experiencing the world (Goodwin & Gotlib, 2004). *Flow* is, in fact, a mixture of different mental states and organizational requirements (Egbert, 2003). Since creativity is, however, described as linked to intrinsic motivation (Csikszentmihalyi, 2000; Baer, 2010; Runco, 2014), genuine interest in the respective subject area may also influence scientific creative processes and, consequently, *act* and *flow*. While the TIMSS 2019 report shows that the gender gap is steadily decreasing (Mullis et al., 2020; Mejía-Rodríguez et al., 2020), the different approach to combining science with art of our participating schools may have influenced results (Baer, 2010; Charyton et al., 2011).

Limitations

One limitation of our study is the self-reporting method of data collection which did not provide us with an "outside" or "independent" perspective on participants' views. Self-reported data are vulnerable to inaccurate reporting as participants may represent themselves differently for a variety of conscious and unconscious reasons. Secondly, our design primarily relies on quantitative data, and is not the type of a multi-trait, multi-method design often regarded most suitable (Leutner et al., 2017). Finally, all data were collected in a single session, and longitudinal tracking of participants was not attempted.

Conclusion

The fact that creative thinking is based on normative cognitive processes emphasizes the need for close collaboration between cognition experts and educational instructors (Kröger 2015). In the context of science learning, productivity and freedom are important triggers of creativity. Gender differences in creative thinking appear more pronounced in certain age groups, and it is, thus, important that appropriate support is available to both genders. The inclusion of different personality traits must also be considered (Csíkszentmihályi et al. 2005). Creative cognitive processes are relevant in multiple educational disciplines – including science teaching – and not just in fields traditionally associated with creativity. Active reflection and the testing of solutions are, thereby, indispensable for science teaching that fosters and supports creativity (Sawyer, 2012). Using direct instruction and hands-on approaches (Boyer & Lamoreaux, 1997) to foster creativity could also be effective in developing scientific skills demanded by future employers (Brynjolfsson & McAfee, 2014). Thus, schools could benefit from integrating creative cognitive processes into curricular revisions for the improvement of science classes (Wyse & Ferrari, 2015). Providing open tasks that leave room for reflection on less restrictive time schedules is one feasible approach to encouraging creative cognitive processes (Yager, 2005). However, much more research is needed to identify best practices for fostering creativity in science education and to assess the extent to which creative cognitive processes are related to other positive outcomes of the school experience (Henriksen et al., 2018). Although the current study is exploratory, it reveals creativity to be an important player in the changing landscape of science education. After all, in a digitalizing world, creativity has the potential to become an indispensable soft skill to put an individual's scientific know-how into practice (Bruno & Canina, 2019).

Acknowledgements Special thanks to the teachers and students involved in this study for their cooperation. Also, many thanks to the Horizon 2020 Framework Program and the German Research Foundation.

Funding Open Access funding enabled and organized by Projekt DEAL.

Declarations

Ethics Approval Hereby, we authors consciously assure that for the manuscript the following is fulfilled:
1) This material is the authors' own original work, which has not been previously published elsewhere.
2) The paper is not currently being considered for publication elsewhere.
3) The paper reflects the authors' own research and analysis in a truthful and complete manner.
4) The paper properly credits the meaningful contributions of co-authors and co-researchers.
5) The results are appropriately placed in the context of prior and existing research.
6) All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference.
7) All authors have been personally and actively involved in substantial work leading to the paper and will take public responsibility for its content.
Moreover, "all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards."

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Conflict of Interest The authors declare no competing interests.

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