Manuscript accepted in Journal of Creative Behavior

Divergent and Convergent thinking across the schoolyears: A dynamic perspective on Creativity Development

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Competing interests

The authors declare no competing interests.

Ethics

This study was approved by the local ethics commission (CER-VD).

Acknowledgement

We are grateful to the children and parents who partook this study. We thank Morgane Budry, Diane Gervaise, Julien Fedrizzi, Claire Batilotti, Marion Décaillet, Coline Grasset, and Amie Chiron for helping with data collection. Imaging was supported in part by the Centre d'Imagerie Biomédicale (CIBM) of the Université de Lausanne (UNIL), Université de Genève (UNIGE), Hôpitaux Universitaires de Genève (HUG), Centre Hospitalier Universitaire Vaudois (CHUV), Ecole Polytechnique Fédérale de Lausanne (EPFL), and the Leenaards and Jeantet Foundations. This research was financially supported by the National Center of Competence in Research in (NCCR) Affective sciences; by the Swiss National

Science Foundation (n°51NF40-104897); by the Boninchi Foundation; by the Fondation Eden in Geneva; by The Société Académique Vaudoise; and by The Prepared Adult Initiative.

ABSTRACT

Creative thinking is critical to overcome many daily life situations. As such, there has been a growing interest on how creative thinking develops across childhood. However, little is known about the underlying mechanisms driving its development. Indeed, almost all research has focused on divergent thinking, leaving aside convergent thinking, and did not thoroughly investigate how internal and/or external factors influence their development. Here, two hundred twenty-two children aged from four to twelve years-old attending either a Montessori or a traditional school performed drawing-based convergent and divergent standardized tasks. In addition, a sub-set of forty-one children were tested using similar tasks for a second session three years apart. The results revealed dynamic developmental stages of convergent and divergent thinking. More specifically, a loss of divergent thinking was counterbalanced by a gain of convergent thinking, especially during the fourth-grade slump (8-10 years-old). Although, Montessori-schooled children showed overall higher creative abilities than traditionally-schooled children, no differences were observed in the developmental trajectories of convergent and divergent thinking between the two pedagogies. This suggests that progress and decrease in creative thinking may be mostly due to internal factors such as brain maturation factors than external factors such as peer-pressure.

INTRODUCTION

We, humans, are special in the animal kingdom. Although we are not physically the fastest nor the most enduring animal, we can travel thousands of kilometres in a couple of hours thanks to sophisticated innovative devices such as airplanes or cars. Critically, creativity plays a key role in the process of innovative behaviors (Rawlings & Legare, 2021). In the present paper, we investigated the developmental trajectories of both divergent and convergent creative thinking in four to twelve-years-old children adopting a cross-sectional and longitudinal framework and explored to what extent the type of pedagogy experienced, either traditional or Montessori, contributed to similarities or changes in these developmental trajectories.

Creative thinking

Creativity is defined as the ability to generate original and useful ideas to overcome constraints (Sternberg & Lubart, 1996). There are two main components involved in creative thinking: divergent (Plucker & Renzulli, 1999) and convergent thinking (Guilford, 1950). Divergent thinking is the process of producing multiple ideas or solutions to solve a specific problem, such as generating alternative uses for a common object (Barbot et al., 2016; Lubart, Besançon & Barbot, 2011). Accordingly, to assess individual divergent thinking level, different standardized tasks have been developed and used, such as the alternative uses task (Beaty & Johnson, 2020) and the alternative drawing-based task (Barbot, 2018; Lubart, Beasançon & Barbot, 2011). In the former, individuals are asked to invent substitute uses for a common object (e.g., a “brick”, a “sock”) whereas in the latter they are asked to generate multiple drawings from a predefined random shape (Barbot et al., 2011). The level of divergent thinking abilities can be quantified based on the participant’s flexibility (i.e., number of different categories mentioned), fluency (i.e., total number of non-redundant ideas produced), and originality (i.e., the uniqueness of the idea). The antagonist of divergent thinking is convergent thinking, which is the process by which multiple thoughts from life experience are assembled in an associative

manner to fit a specific problem (Guilford, 1950). There are several standardized convergent thinking tasks, such as drawing-based tasks where individuals are instructed to create a drawing that integrates a given number of abstract shapes with a score based on the originality of the idea, the quality of shapes' integration, and the storytelling dimension. (Barbot et al., 2011).

Divergent thinking development

Creative thinking has a long history in developmental research (e.g., Hammershøj, 2021; Miller & Gerard, 1979), though much remains to be done to understand how precisely it develops across childhood given that most developmental research is based on divergent creative thinking tasks (Barbot et al., 2016). I**Erreur ! Signet non défini.**nterestingly, research using the latter tasks has identified a non-linear developmental pattern throughout childhood (Said-Metwaly et al., 2021). Indeed, a longitudinal study observed an overall increase in divergent thinking ability but with three slumps or decreases in performance occurring at age five, nine and twelve (Torrance, 1968). More specifically, the slump at age nine, also known as the fourth grade slump, has arisen great interest with studies reporting its presence (Barbot et al., 2018; Raina et al., 1980; Saggar et al., 2019; Timmel, 2001) whereas other studies have reported its absence (Charles & Runco, 2010; Jaarsveld et al., 2012; Lau & Cheung, 2010; Sak & Maker, 2006) or only a slight bump at this age (Claxton et al., 2005). Indeed, a recent meta-analysis failed to find evidence of the fourth grade slump (Said-Metwaly et al., 2021). However, such discrepancies between studies are not surprising given that in the seminal work of Torrance (1968), only half of the fourth graders showed a slump. As such, inter-individual differences as well as differences in the experimental settings (i.e., longitudinal versus cross-sectional design, specificities of the task) may play a large role in the observation or not of the fourth grade slump across studies and call for more research to better understand the discrepancies in these findings.

Convergent thinking development

Conversely, little is known on the developmental trajectory of convergent thinking, as it arose less interest among researchers in creative thinking development (Runco & Acar, 2019). However, there is some suggestive evidence that convergent thinking may follow a steady increase in performance across childhood. Indeed, using a cross-sectional procedure, Guignard & Lubart (2016) observed that both gifted and non-gifted children (i.e., IQ more than and less than 130, respectively) showed an increase in performance for convergent thinking from the 5th grade to 7th grade. Conversely, for divergent thinking strong individual differences were reported between the two groups with no difference between the grades for gifted children and an increase from the lower to the higher grade for non-gifted children. Interestingly, a recent study used a convergent thinking task to analyze the fourth grade slump and found no decrease (Gralewski et al., 2016). This suggests that convergent thinking may have a steadier increase across childhood than divergent thinking (which has different slumps), potentially due to individual differences.

Role of internal factors on divergent and convergent thinking

Convergent and divergent thinking may rely on distinct internal and cognitive processes with a developmental peak at different cognitive stages and age. Many scholars have described that children go through successive cognitive stages leading up to abstract thinking (Fischer, 1980; Montessori, 1936; Piaget, 1952, 1954). For instance, up to seven years of age, children explore their environment to gain knowledge (Piaget, 1952), encoding information through experience (Gitten et al., 2006). This process is named associative learning and may be related to the early increase in convergent thinking, possibly paralleled by the emergence of divergent thinking. Then, children enter the concrete operational stage where thoughts are reasoned and converge. While this period could hinder the emergence of original ideas – as reflected by the fourth grade slump in divergent thinking abilities (Torrance, 1968)—it could be related to a gain in convergent thinking abilities. After the fourth grade, children can use ideas in an

unconventional manner (Piaget, 1954) leading teenagers to switch between dependency from their parents to social autonomy (Kleibeuker et al., 2013). This switch impacts their explorative abilities and may explain the peak in divergent creative thinking observed by mid-adolescence (15-16-years-old; Kleibeuker et al., 2013; Stevenson et al., 2014).

Role of external factors on divergent and convergent thinking

Besides internal factors, several external factors might explain the developmental trajectories of divergent and convergent thinking. For instance, it is thought that the variations in the observation of the fourth-grade slump could be due to peer pressure and the need to conform to social norms, as encountered at school. In fact, social settings impact creative thinking and contribute to individual differences (Amabile et al., 1996; Camarda et al., 2021; Paulus & Dzindolet, 2008). One particular setting where children spend most of their time is at school but this aspect has never been investigated in previous research. Critically, two different school pedagogies can be opposed. On the one hand, traditional pedagogy where children experience a more normative environment with same-age classes, a regulated curricula that was decided in advance and directed by a teacher, as well as tests that are given in order to assess children's performance which favors competition between peers (Hayek et al., 2017), may limit their creative potential (Dineen & Niu, 2008). On the other hand, the Montessori pedagogy (Lillard et al., 2017; Marshall, 2017; Montessori, 1936), among other alternative pedagogies (e.g., Freinet, Waldorf), is a school setting where children are in a less-pressured learning environment with multi-age classes, a less regulated curricula, no grades, and favors peer-to-peer cooperation. This is encouraged by using associative learning until the age of six years where children take on activities and must make choices on their own to find a solution which could favor the growth of convergent thinking. From the age of six years, explorative learning is enhanced using all the knowledge acquired through exploration and experience by collaborating with other classmates which is key for the effectiveness of divergent thinking.

This environment has been shown to favor creative thinking (Besançon & Lubart, 2007; Lillard & Else-Quest, 2006), independently of cognitive control and fluid intelligence abilities (Denervaud et al., 2019). Therefore, investigating both divergent and convergent thinking in different school settings might shed new lights on our understanding of the development of creative thinking.

The present study

Taken together, there may be an overall dynamic process where divergent thinking decreases in favor of convergent thinking across childhood. If true, children benefitting from an environment nurturing successively these modes of thinking, such as in the Montessori pedagogy, would reinforce their creative thinking abilities. However, the use of limited sample sizes with little clear variations between individuals, cross-sectional approaches over longitudinal approaches coupled with the intense focus on divergent thinking (see Runco & Acar, 2019) have limited a more thorough investigation of creative thinking as a dynamic process. Consequently, in the present paper, we first tested a sample of two hundreds twenty-two children aged from 4 to 12 years-old in both convergent and divergent creative thinking tasks adopting a cross-sectional approach (for a similar approach, see Jaarsveld et al., 2012). Furthermore, we explored the role played by the pedagogy experienced by comparing within this sample, children either enrolled in traditional schools or Montessori schools. We then adopted a longitudinal approach by testing a sub-set of forty-one of these children two to three years later using the same tasks to attempt to provide a clearer developmental picture of the development of creative thinking. From these forty-one children, another sub-set of twenty-six children were included in the investigation of the fourth grade slump. We hypothesized that creative thinking would follow a dynamic development where convergent and divergent thinking abilities fluctuate differently across childhood. More specifically, we expected to observe in the cross-sectional and longitudinal datasets different developmental trajectories of

convergent and divergent thinking, which would be evidenced by a potential decrease of divergent thinking coupled with an increase of convergent thinking in 6 to 12 years-old (Barbot et al., 2016; Guignard & Lubart, 2016; Raina et al., 1980; Saggar et al., 2019; Timmel, 2001; Torrance, 1968). Importantly, if the fourth-grade slump was present in our data (Said-Metwaly et al., 2021), we expected the compensation of convergent thinking over divergent thinking to be especially magnified during this age period. Finally, we hypothesized that creative thinking (both convergent and divergent thinking) could be modulated by school pedagogy, with Montessori-schooled children showing overall greater creative thinking abilities than traditionally-schooled children, as reported in previous work (Besançon & Lubart, 2007; Denervaud et al., 2019), with potentially a reduction of the fourth-grade slump in the former than in the latter.

MATERIAL & METHOD

Participants

A total of two hundreds twenty-two typically developing children from 4 to 12 years-old (M_{age} = 8.79 years-olds, SD_{age} = 2.20 years-old, age range = 4.3-12.8 years-old, 109 females) took part in this study. Participants were recruited within multiple schools across Switzerland, and from two different types of pedagogies. One hundred and four children were enrolled in Montessori schools (M_{age} = 8.69 years-old, SD_{age} = 2.27 years-old, age range = 4.3-12.8 years-old, 44 females) and one hundred eighteen participants were enrolled in traditional schools (M_{age} = 8.88 years-old, SD_{age} = 2.14 years-old, age range = 4.6-12.8 years-old, 65 females).

Out of these two hundreds twenty-two children, forty-one children aged six- to twelve-years-old (M_{age} = 9.42 years-old, SD_{age} = 1.81 years-old, age range = 5.9-12.8 years-old, 22 females), came back for a second session between two and three years later. The legal guardian

of the participant filled in a written consent form. This study was approved by the local ethics commission.

Material and procedure

All children were tested either at the lab or in schools, in a quiet and dedicated room. All tasks were paper-based, and the duration of the experiment was of 1 hour.

Group variables

Children enrolled in this study came from public traditional or private Montessori learning environments. Given that Montessori schools in Switzerland are private systems only, group variables were collected to ensure group homogeneity on fluid intelligence and socio-economic backgrounds.

Fluid intelligence was measured through a black-and-white version of the Raven's Progressive Matrices (PM-47) test (Raven et al., 1998), composed of 36 incomplete matrices. For each matrix, the participant was presented with six possible patterns, and asked to select one to complete the missing part. The time limit was set to 15 minutes. To score fluid intelligence, correct answers were summed (score range: 0 to 36).

The socio-economic status (SES) was assessed through a parental questionnaire. Parents were asked to complete a form about their educational and professional levels (Genoud, 2011). The answers given from each parent were rated from one to four, summed and then averaged. For the educational level, each parent was asked about the degree they completed (0 was attributed to no degree and 4 to PhD or higher). For the professional level, each parent had to wright their job and a specified table was used to rate their job. In the case where the child was under biparental authority, the average of both parents was computed. In the case of mono parental authority, the score was computed based on the answers from the legal guardian. Then, the scores were normalized (score range: 0 to 1).

Creative thinking measures

Standardized drawing paper-based tasks were used to assess convergent and divergent thinking (Evaluation of Potential Creativity battery; Lubart, Besançon & Barbot, 2011).

Convergent creative thinking task

The child was asked to draw on a sheet of paper the most creative drawing as possible by including at least 3 of the 8 abstract shapes (e.g., an oval) within a predefined time of 10 minutes. The task had shapes used in common drawings (e.g., a square and a triangle to draw a house) to differentiate more creative children who used these shapes to draw something else from less creative children who drew a house. To assess convergent thinking, each drawing was rated on a scale from 1 (i.e., low creativity drawing) to 7 (i.e., high creativity drawing). Based on the experimental manual (Evaluation of Potential Creativity battery; Lubart, Besançon & Barbot, 2011), this was done by three blind independent trained raters who were instructed to rate each drawing by taking into consideration the integration of shapes (i.e. the shapes were used appropriately in the child's drawing), originality (i.e. did the child draw something different from other children), and storytelling (i.e. if the child was able to share a story through its drawing). Inter-rater agreement was assessed by using the percent agreement for multiple raters. For each drawing, there were three different combinations possible between the raters (i.e., R1/R2, R1/R3, R2/R3). For each combination, if two raters agreed with each other on the score, they would receive 1 point and 0 if they disagree. A maximum of 3 points would be possible for each drawing. To calculate the percentage of agreement, the sum was used and divided by the total of combinations (i.e., 3 times the number of participants). This percentage was evaluated as good (67%).

Divergent creative thinking task

The child was instructed to draw as many different drawings as possible from an abstract shape within a predefined time of 5 minutes. As for the convergent drawing task, the child was asked to be as creative as possible. To rate divergent thinking, the sum of each valid drawing was applied, i.e., a concrete and unique drawing where the initial given shape was used. If the child used the shape for the same idea in two separate drawings, only one drawing was counted. This task had no maximum.

Statistical analyses

R Studio (R Studio Team, 2020) and Jamovi (https://www.jamovi.org/) were used to perform the statistical analyses.

Group variables

Age, sex, fluid intelligence, and SES were collected to verify homogeneity between the two groups (i.e., Montessori and traditional) as those variables can influence creative thinking (Beaty et al., 2014; Castillo-Vergara et al., 2018; Mouchiroud & Lubart, 2016; Piaw, 2014). Firstly, the normality of the data was tested through Shapiro-Wilk tests on age, fluid intelligence, and SES. If $p > .05$, Student's t-tests were applied, however if $p < .05$, Welch's t-tests were performed. Finally, a chi-square test was done to verify whether the sex ratio was comparable between the two groups. These statistical analyses were performed on the cross-sectional and longitudinal data.

Creative thinking measures

The proportion of maximum scaling (POMS) method (Little, 2013) was applied to allow comparison between convergent and divergent thinking scores. This method scales measures from 0 to 1 as follow: POMS = [(observed − minimum)/(maximum − minimum)].

First, the cross-sectional data was analyzed using an ANalysis of COVAariance (ANCOVA) on POMS scores of creative thinking, with form of creative thinking (convergent, divergent) and pedagogy (Montessori, traditional) as factors, age as a covariate and all interactions terms. For each *p*-value lower than .05, post-hoc comparisons were performed, with Tukey correction.

Second, the longitudinal data was analyzed using a repeated measures ANOVA (rmANOVA) on the POMS scores of creative thinking at each timepoint (timepoint 1, timepoint 2) with the form of creative thinking (convergent, divergent) as within-subjects factor, and pedagogy (Montessori, traditional) as between-subjects factor. As for the cross-sectional data, post-hoc comparisons were performed if $p < .05$.

Furthermore, an exploratory analysis on a sub-set of 26 participants (age range: 8.0-10.8 years-old.; M_{age} = 9.55 years-old, SD_{age} = 0.93; 15 females) from the longitudinal data was performed to explore the extent to which divergent thinking loss was related to an increase of convergent thinking during the fourth-grade slump (8-10 years-old). A paired samples t-test was used to compare convergent and divergent thinking between timepoints.

RESULTS

Control variables

Table 1 – Demographics and control variables for the cross-sectional data

	Montessori	Traditional	Statistical tests
N (F)	104 (44)	118 (65)	χ^2 (1,222) = 0.07, p = .788
Age (SD)	8.69 (2.28)	8.88 (2.15)	t(213) = -0.62, p = .535

	Montessori	Traditional	Statistical tests
Age range	4.37-12.80	4.62-12.80	
Fluid intelligence	30.40 (7.08)	29.50 (6.41)	$t(209) = 0.98$, $p = .328$
SES	0.71 (0.11)	0.71 (0.12)	$t(217) = -0.40$, $p = .686$

For the cross-sectional data, Shapiro-Wilk tests showed a violation of normality for all three variables (p-values < .001) and Welch t-tests were applied for group comparison. The analyses did not reveal any group difference between Montessori-schooled children and traditionally-schooled children for all control variables (Table 1).

Table 2 – Demographics and control variables for the longitudinal data

	Montessori	Traditional	Statistical tests
N (F)	17 (9)	24 (13)	$\chi^2 (1,41) = 0.22$, $p = .639$
Age at T1 (SD)	9.29 (1.87)	9.41 (1.81)	$t(39) = -0.20$, $p = .842$
Age range at T1	5.92-12.70	6.00-12.80	
Age at T2 (SD)	12.2 (1.90)	12.3 (1.85)	$t(39) = -0.09$, $p = .926$
Age range at T2	8.80-15.80	8.40-15.70	
Fluid intelligence at T1	32.9 (3.95)	31.8 (3.76)	$t(39) = 0.85$, $p = .399$
Fluid intelligence at T2	34.5 (2.67)	34.1 (1.67)	$t(39) = 0.53$, $p = .601$
SES at T1	3.11 (0.37)	2.90 (0.58)	$t(38) = 1.44$, $p = .159$
SES at T2	3.21 (0.51)	2.94 (0.60)	$t(37) = 1.47$, $p = .149$

For the longitudinal data, Shapiro-Wilk tests revealed a non-violation of normality for age at timepoint 1 (T1; $p = .485$) and age at timepoint 2 (T2; $p = .714$), Student's t-tests did not reveal any group difference between Montessori-schooled children and traditionally-schooled

children for age at T1 and T2 (Table 2). However, there was a violation of normality for fluid intelligence and SES at both timepoints (*p*s < .004) and Welch t-tests were performed for group comparison, revealing no group differences between Montessori-schooled children and traditionally-schooled children for fluid intelligence at T1 and T2, and SES at T1 and T2 (Table 2).

These results indicated that the groups were homogeneous on these measures for the cross-sectional and longitudinal analyses.

Convergent and divergent thinking

Cross-sectional data.

The ANCOVA on the cross-sectional data yielded significant main effects of form of creative thinking, $F(1,433) = 11.96$, $p < .001$, $\eta_p^2 = 0.027$, pedagogy, $F(1,433) = 4.51$, $p = .034$, $\eta_p^2 = 0.010$, and age, $F(1,433) = 105.68$, $p < .001$, $\eta_p^2 = 0.196$. These effects indicated convergent thinking performance ($M = 0.58$, $SD = 0.24$) was higher than divergent thinking performance ($M = 0.48$, $SD = 0.30$), the overall creative thinking performance was higher for Montessori-schooled children ($M = 0.63$, $SD = 0.27$) than for traditionally-schooled children ($M = 0.44$, $SD = 0.25$), and significantly increased as children gain age. We observed a significant interaction between form of creative thinking and age, $F(1,433) = 5.85$, $p = .016$, $\eta_p^2 = 0.013$ (Figure 1), revealing that divergent thinking and convergent thinking follow different trajectories which could be reflected by a slump in divergent thinking and a bump in convergent thinking. No other interaction terms were significant ($p > .288$).

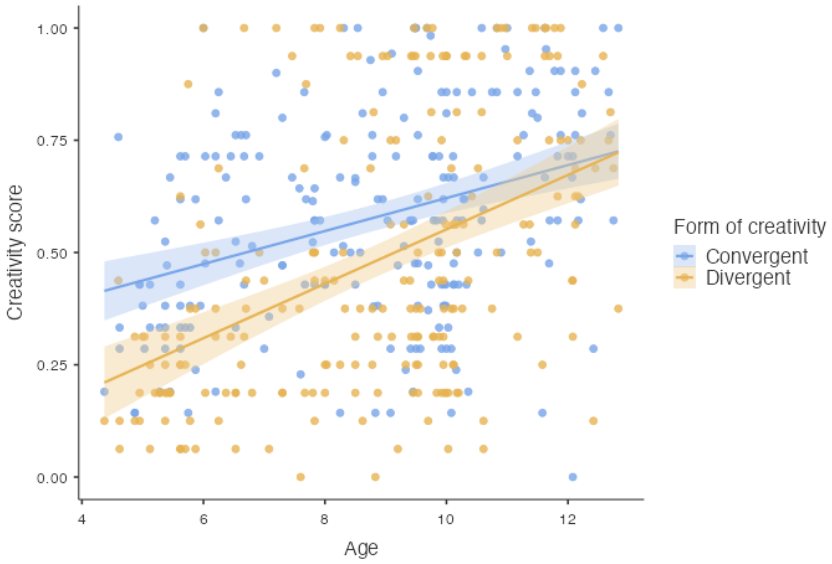

Figure 1 – POMS creative thinking scores as a function of age grouped by form of creative thinking. Convergent thinking is higher in younger children then divergent thinking catches up during early adolescence.

Longitudinal data

A rmANOVA was used to compare the effect of the form of creative thinking and pedagogy between the two timepoints (T1 and T2) on all longitudinal data (N = 41). This analysis revealed main effects of the form of creative thinking, $F(1,39) = 17.50$, $p < .001$, $\eta_p^2 = 0.310$, and pedagogy, $F(1,39) = 21.00$, $p < .001$, $\eta_p^2 = 0.350$. Overall, convergent thinking ($M = 0.60$, $SD = 0.23$) had a higher mean value than divergent thinking ($M = 0.45$, $SD = 0.27$), and Montessori-schooled children ($M = 0.64$, $SD = 0.25$) scored higher than traditionally-schooled children ($M = 0.46$, $SD = 0.22$). Although, there was no main effect of the timepoint, $p = .184$, we nevertheless observed a significant two-way interaction between timepoint and form of creative thinking, $F(1,39) = 25.64$, $p = < .001$, $\eta_p^2 = 0.397$. This interaction revealed that convergent thinking was significantly higher at timepoint 2 ($M = 0.70$, $SD = 0.17$) than at timepoint 1 ($M = 0.51$, $SD = 0.25$), $t(39) = -4.34$, $p < .001$, but divergent thinking was not

significantly different between timepoint 1 (M = 0.49, SD = 0.31) and timepoint 2 (M = 0.41, SD = 0.21), $t(39) = 2.17$, $p = .151$ (Figure 2). No other interaction term was significant ($p > .103$).

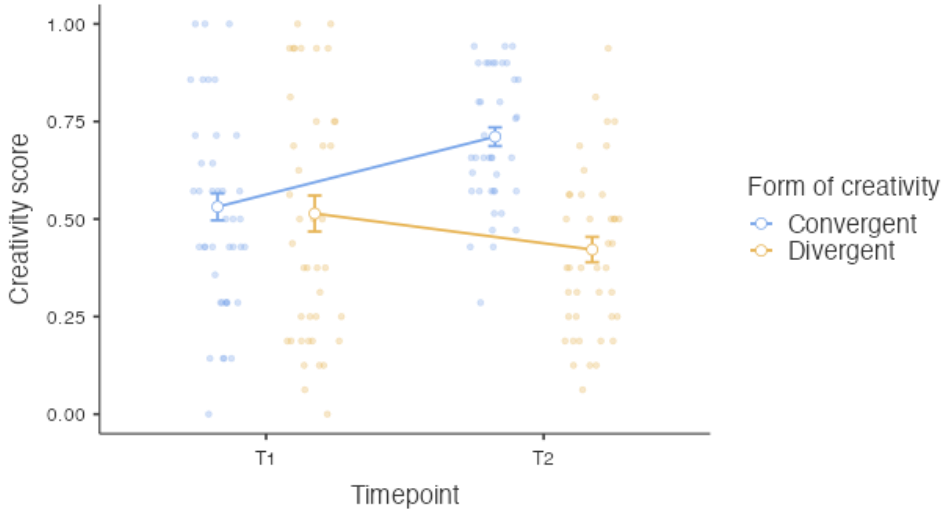

Figure 2 – Interaction between timepoint and creative thinking score. Convergent thinking shows an increase between timepoint 1 and timepoint 2 whilst divergent thinking shows a decrease between the timepoints.

Longitudinal analysis of the fourth grade slump

While plotting the longitudinal data, an obvious loss of divergent thinking and gain of convergent thinking was observed across the fourth grade slump (Figure 3). We therefore extracted a sub-set group of twenty-six children (M_{age} = 9.55 years-old, SD_{age} = 0.93 years-old, age range = 8.0-10.8 years-old, 15 females) to explore the extent to which divergent thinking loss was related to an increase of convergent thinking during the fourth-grade slump (8-10 years-old).

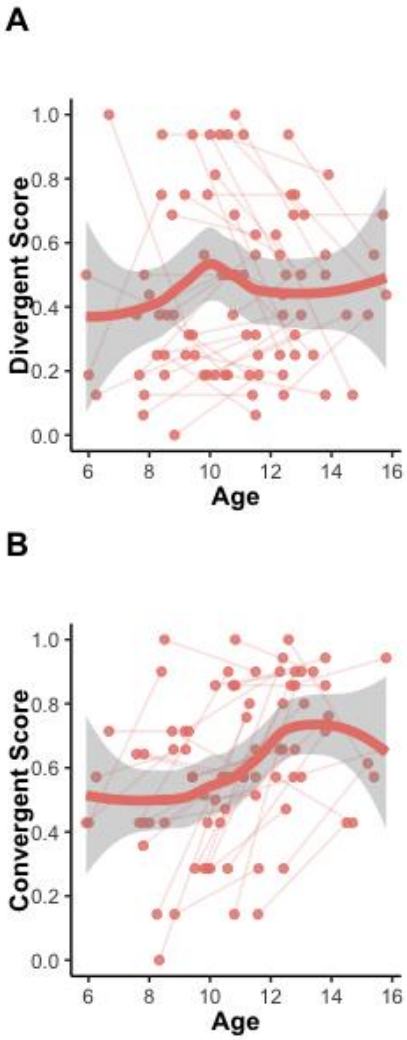

Figure 3 – Longitudinal data. A. POMS scores of divergent thinking. B. Raw scores of convergent thinking.

A paired samples t-test was used to compare convergent and divergent thinking between timepoints, 16 showed a loss between timepoints in divergent thinking and 22 showed a gain in convergent thinking between timepoints. On average, divergent thinking was significantly lower at timepoint 2 (M = 0.41, SD = 0.22) than timepoint 1 (M = 0.53, SD = 0.31), $t(25)$ = 2.51, p = .02. The decrease of divergent thinking was balanced by a significant increase of convergent thinking at timepoint 2 (M = 0.72, SD = 0.17) over timepoint 1 (M = 0.49, SD = 0.46), $t(25)$ = -4.39, p < .001; Figure 4.

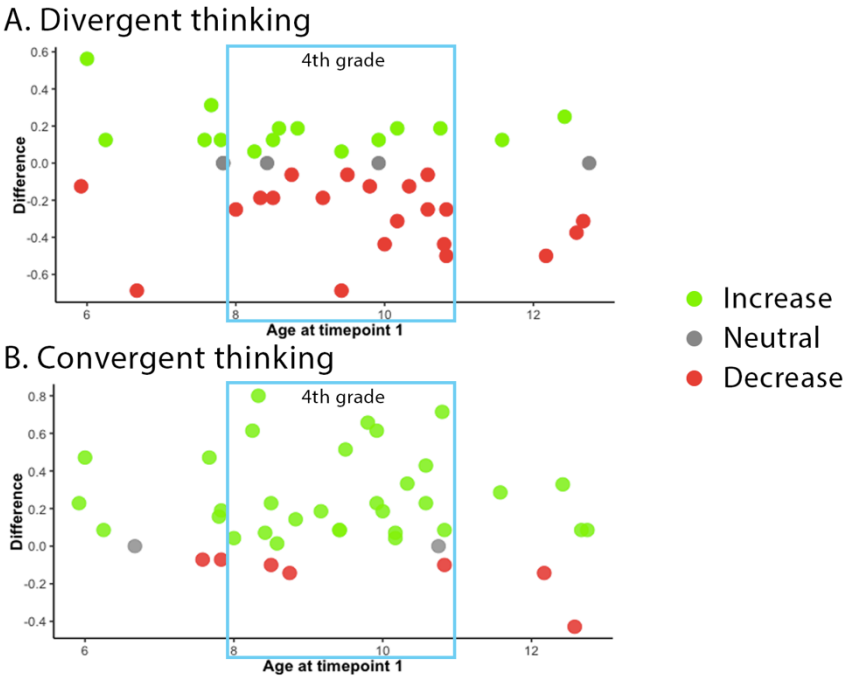

Figure 4 – Evolution of divergent thinking (A) and convergent thinking (B) between timepoint 1 and timepoint 2. The dots indicate the differences from T2 to T1 (green = increase, red = decrease and gray = no gain or loss).

DISCUSSION

A lack of studies investigating both convergent and divergent thinking across the school years has limited the understanding of creative thinking's slumps and bumps throughout childhood. It was unknown whether these fluctuations reflect maturational processes, environmental influences, or both. Here, we investigated for the first time in a single study both convergent and divergent thinking across childhood (from 4 to 12 years-old) using a large cross-sectional dataset and a sub-set of longitudinal data, and explored to what extent an environmental factor, namely school pedagogy, contributes to the development of these forms of creative thinking.

Consistent with our first prediction, we reported different developmental patterns for convergent and divergent thinking at the cross-sectional and longitudinal levels. Indeed, the cross-sectional analysis showed a higher level of convergent thinking over divergent thinking

early during development. These results were confirmed with our longitudinal analyses. The early increase in convergent thinking could be explained by younger children acquiring knowledge by experiencing the environment they are in and learning by associating different concepts together (e.g., Denervaud et al., 2021). The higher level of convergent thinking over divergent thinking in younger children (~4-10 years-old) can be related to the inability of these children to efficiently think in an abstract manner (Fischer, 1980; Snyder & Munakata, 2010, 2013). Accordingly, at the age of 12 years, divergent thinking reached the same level as convergent thinking in the cross-sectional analysis. The longitudinal analysis confirmed this observation with divergent thinking showing a stronger increase than convergent thinking which leads divergent thinking to catch up with convergent thinking when children grow up. One possible explanation for this would be the increasing gain in general knowledge and abstract abilities (Munakata et al., 2012) underlying a better ability to self-directed switch from one concept to another unrelated concept (e.g., Sauzéon et al., 2004). This could explain why divergent thinking increases more than convergent thinking during this period.

Additionally, we observed that the well-established decrease in divergent thinking (Torrance, 1968) was related to an increase in convergent thinking, especially during the fourth grade's slump. This seems to confirm that there is no fourth grade slump for convergent thinking (Gralewski et al., 2016; Jaarsveld et al., 2012). However, our results indicated that there was a fourth grade slump for divergent thinking, although such slump is not consistently reported (Said-Metwaly et al., 2021), potentially due to different methodological approaches. Nevertheless, this slump was thought to be caused by social norms and peer pressure experienced at school (Saggar et al., 2019; Torrance, 1968), therefore we hypothesized that different school pedagogies may modulate this decrease of divergent thinking. However, contrary to our expectations, we observed that although Montessori-schooled children showed better creative thinking abilities than traditionally-schooled children, in line with previous

findings (e.g., Besançon & Lubart, 2007; Denervaud et al., 2019), the former who experience an environment with an absence of peer pressure and social norms (i.e. Montessori pedagogy), showed a similar loss of divergent thinking during fourth grade as well as a bump of convergent thinking than children experiencing an environment with peer pressure and social norms (i.e. traditional pedagogy). This strongly suggests that the decrease in divergent thinking and increase in convergent thinking could be more related to maturational processes occurring at these ages (e.g., functional connectivity between the prefrontal cortex and the default mode network, Fan et al., 2021) and less dependent on life experience such as schooling. One explanation for this phenomenon could be the increase of one form of creative thinking as a compensatory process to the decrease of the other. Indeed, a decrease of one form of creative thinking is not necessarily synonymous to an overall decrease of creative thinking. Maybe, this decrease could be due to an increase of the other occurring because of maturational processes. Another explanation could be the ability of children to change beyond social norms and peer pressure at these ages as thought earlier, following the concrete developmental stage (Fischer et al., 1980; Piaget, 1954). During this stage, children's thoughts become logical and organized which would in turn not support the emergence of original ideas (i.e., decrease of divergent thinking). This shift in the way thoughts emerge means that environmental influences, such as social norms and peer pressure, may not impact the development of creative thinking during these ages. It could be due to the ability of children to change. However, the possibility of school pedagogy impacting convergent and divergent thinking during the fourth grade should not be excluded. Indeed, it could be due to both traditional and Montessori schools unintentionally focuse more on convergent tasks rather than divergent tasks in their school activities (e.g., finding the most appropriate solution to a problem) which could in turn explain this increase in convergent thinking. More work is needed to answer these questions. So far, our findings suggest considering the development of convergent and divergent thinking as

dynamic and to be studied separately. Additionally, creative thinking should not be referred by only one of these forms when studying it in children. Through these results, we were able to replicate previous work reporting a non-linear development in divergent thinking which goes through slumps and bumps (Saggar et al., 2019). Moreover, we reported that lower divergent thinking abilities seem to be compensated by an increase in convergent thinking.

Critically, as mentioned previously, although Montessori-schooled children go through the same developmental slumps and bumps of convergent and divergent thinking than traditionally-schooled children, they nevertheless outperformed the latter in both the cross-sectional and longitudinal analyses (Besançon & Lubart, 2007; Denervaud et al., 2019). One possible explanation for this outcome relates to the specificities of the Montessori pedagogy, which emphasizes self-exploration (i.e., self-directed work and active learning) and exerts less pressure by the teacher and classmates (i.e., no formal assessment, grade, homework). In this environment, Montessori-schooled children may follow the same dynamic changes in their creative thinking than traditional-schooled children, but the former may better fulfill their creative thinking potential. The fact that we did not observe a greater increase of creative thinking across development in Montessori-schooled children, nor a catch-up by traditionally-schooled peers, may indicate that creative potential may be nurtured early during development and continue its trajectory over time. If confirmed, it points the importance of fostering creative thinking abilities in the early years of development.

Limitations

Several limitations need to be acknowledged. First, our findings should be replicated in countries where traditional schools use a different educational system. All the children in this study attended a school in Switzerland. Countries such as Sweden, as an example, have traditional schools that resembles to Montessori schools and cultural differences between countries have been shown to impact the performance on creativity tasks (Shao et al., 2019).

Second, more creative parents may be more inclined to send their children to schools using alternative pedagogies (e.g., Montessori, Freinet, Waldorf) which could explain higher creative thinking abilities in Montessori-schooled children. Third, regarding the dynamic development of creative thinking, extending the current sample to children younger than 4 years-old and older than 12 years-old with a longitudinal approach would allow to better capture both early development of creative thinking and how divergent thinking develops after the fourth grade. Then, we reckon that both external factors such as home environment and internal factors such as personal motivation can influence how a child perform on a creative thinking task. For instance, the creative thinking task used here were drawing-based tasks, and it could have been informative to have a measure of how often each child engage in a similar activity either at home or at school. There can be multiple factors influencing a child's performance during a creative thinking task such as fatigue, motivation, personal interest and so on. Therefore, future work should take into consideration these aspects to better approach creativity development. Fourth, as previously mentioned, the children performed drawing-based tasks, whereas there are different tasks measuring creative thinking such as verbal and graphic tasks. Due to limited time, we chose to use only drawing-based tasks, but future work should make use of different methods to allow for a better generalization of the results. Finally, we acknowledge that our longitudinal approach might have some weaknesses. Indeed, due to the difficulty of tracking children over a long period of time, we were able to test only forty-one out of the two hundreds twenty-two children initially tested. Therefore, we mind the readers about the generality of our results and call for future research adopting a longitudinal approach. Moreover, although the longitudinal findings were backed up with the cross-sectional findings, we reckon that having only two data points in the longitudinal approach to track dynamic developmental changes might not be ideal and we encourage future longitudinal studies to increase the number of these data points to better capture these changes.

Conclusions

To conclude, the main contribution of the present paper is to suggest in a single cross-sectional and longitudinal study that convergent and divergent thinking may follow different developmental trajectories. More specifically, we reported a fourth-grade slump in divergent thinking (but see Said-Metwaly et al., 2021), but also found suggestive evidence that this decrease was compensated by an increase of convergent thinking. Finally, we observed this dynamic relation between convergent and divergent thinking in the development to be similar in children coming from different school pedagogies, suggesting an important role of maturational neural and/or cognitive processes in the developmental paths of these two forms of creative thinking. However, the possibility of school pedagogy impacting this dynamic relation should not be excluded as Montessori children outperformed traditionally-schooled children. Future work is needed to better unveil the developmental path of creative abilities and how to foster them.

REFERENCES

Amabile, T. M., Conti, R., Coon, H., Lazenby, J., & Herron, M. (1996). Assessing the work environment for creativity. *Academy of Management Journal*, *39*(5), 1154–1184. https://doi.org/10.2307/256995

Barbot, B. (2018). The dynamics of creative ideation: Introducing a new assessment paradigm. *Frontiers in Psychology*, *9*, 2529. https://doi.org/10.3389/fpsyg.2018.02529

Barbot, B., Besançon, M., & Lubart, T. I. (2011). Assessing Creativity in the Classroom. *The Open Education Journal*, *4*(1), 58–66. https://doi.org/10.2174/1874920801104010058

Barbot, B., Lubart, T. I., & Besançon, M. (2016). "Peaks, Slumps, and Bumps": Individual Differences in the Development of Creativity in Children and Adolescents. *New Directions for Child and Adolescent Development*, *2016*(151), 33–45.

https://doi.org/10.1002/CAD.20152

Beaty, R. E., Nusbaum, E. C., & Silvia, P. J. (2014). Does insight problem solving predict real-world creativity? *Psychology of Aesthetics, Creativity, and the Arts*, *8*(3), 287–292. https://doi.org/10.1037/A0035727

Beaty, R., & Johnson, D. (2020). Automating Creativity Assessment with SemDis: An Open Platform for Computing Semantic Distance. *Behavior Research Methods*, *53*, 757–780. https://doi.org/doi.org/10.3758/s13428-020-01453-w

Besançon, M., & Lubart, T. (2007). Differences in the development of creative competencies in children schooled in diverse learning environments. *Learning and Individual Differences*, *18*(4), 381–389. https://doi.org/10.1016/j.lindif.2007.11.009

Camarda, A., Bouhours, L., Osmont, A., Le Masson, P., Weil, B., Borst, G., & Cassotti, M. (2021). Opposite Effect of Social Evaluation on Creative Idea Generation in Early and Middle Adolescents. *Creativity Research Journal*, *33*(4), 399–410. https://doi.org/10.1080/10400419.2021.1902174

Castillo-Vergara, M., Barrios Galleguillos, N., Jofré Cuello, L., Alvarez-Marin, A., & Acuña-Opazo, C. (2018). Does socioeconomic status influence student creativity? *Thinking Skills and Creativity*, *29*, 142–152. https://doi.org/10.1016/J.TSC.2018.07.005

Charles, R. E., & Runco, M. A. (2010). Developmental Trends in the Evaluative and Divergent Thinking of Children. *Creativity Research Journal*, *13*(3–4), 417–437. https://doi.org/10.1207/S15326934CRJ1334_19

Claxton, A. F., Pannells, T. C., & Rhoads, P. A. (2005). Developmental trends in the creativity of school-age children. *Creativity Research Journal*, *17*(4), 327–335. https://doi.org/10.1207/S15326934CRJ1704_4

Denervaud, S., Christensen, A. P., Kenett, Y. N., & Beaty, R. E. (2021). Education shapes the structure of semantic memory and impacts creative thinking. *Npj Science of Learning*, *6*,

35. https://doi.org/10.1038/s41539-021-00113-8

Denervaud, S., Knebel, J. F., Hagmann, P., & Gentaz, E. (2019). Beyond executive functions, creativity skills benefit academic outcomes: Insights from Montessori education. *PLoS ONE*, *14*(11), 1–13. https://doi.org/10.1371/journal.pone.0225319

Dineen, R., & Niu, W. (2008). The Effectiveness of Western Creative Teaching Methods in China: An Action Research Project. *Psychology of Aesthetics, Creativity, and the Arts*, *2*(1), 42–52. https://doi.org/10.1037/1931-3896.2.1.42

Fan, F., Liao, X., Lei, T., Zhao, T., Xia, M., Men, W., Wang, Y., Hu, M., Liu, J., Qin, S., Tan, S., Gao, J. H., Dong, Q., Tao, S., & He, Y. (2021). Development of the default-mode network during childhood and adolescence: A longitudinal resting-state fMRI study. *NeuroImage*, *226*, 117581. https://doi.org/10.1016/J.NEUROIMAGE.2020.117581

Fischer, K. W. (1980). A Theory of Cognitive Development: The Control and Construction of Hierarchies of Skills. *Psychological Review*, *87*(6), 477–531. https://doi.org/10.1037/0033-295X.87.6.477

Genoud, P. A. (2011). Indice de position socioéconomique: un calcul simplifié. *Fribourg : Université de Fribourg*. www.unifr.ch/cerf/ipse

Gitten, J. C., Winer, J. L., Festa, E. K., & Heindel, W. C. (2006). Conditional associative learning of spatial and object information in children with attention deficit/hyperactivity disorder. *Child Neuropsychology : A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *12*(1), 39–56. https://doi.org/10.1080/09297040500205579

Gralewski, J., Lebuda, I., Gajda, A., Jankowska, D. M., & Wiśniewska, E. (2016). Slumps and Jumps: Another Look at Developmental Changes in Creative Abilities. *Creativity. Theories – Research - Applications*, *3*(1), 152–177. https://doi.org/10.1515/CTRA-2016-0011

Guignard, J. H., & Lubart, T. I. (2016). A Comparative Study of Convergent and Divergent

559 Thinking in Intellectually Gifted Children. *Gifted and Talented International*, *22*(1), 9–
560 15. https://doi.org/10.1080/15332276.2007.11673481
561 Guilford, J. P. (1950). Creativity. *American Psychologist*, *5*, 444–454.
562 https://psycnet.apa.org/record/1951-04354-001
563 Hammershøj, L. G. (2021). Creativity in children as play and humour: Indicators of affective
564 processes of creativity. *Thinking Skills and Creativity*, *39*, 100784.
565 https://doi.org/10.1016/J.TSC.2020.100784
566 Hayek, A. S., Toma, C., Guidotti, S., Oberlé, D., & Butera, F. (2017). Grades degrade group
567 coordination: deteriorated interactions and performance in a cooperative motor task.
568 *European Journal of Psychology of Education*, *32*(1), 97–112.
569 https://doi.org/10.1007/s10212-016-0286-9
570 Jaarsveld, S., Lachmann, T., & van Leeuwen, C. (2012). Creative reasoning across
571 developmental levels: Convergence and divergence in problem creation. *Intelligence*,
572 *40*(2), 172–188. https://doi.org/10.1016/J.INTELL.2012.01.002
573 Kleibeuker, S. W., De Dreu, C. K. W., & Crone, E. A. (2013). The development of creative
574 cognition across adolescence: distinct trajectories for insight and divergent thinking.
575 *Developmental Science*, *16*(1), 2–12. https://doi.org/10.1111/J.1467-7687.2012.01176.X
576 Lau, S., & Cheung, P. C. (2010). Developmental Trends of Creativity: What Twists of Turn
577 Do Boys and Girls Take at Different Grades? *Creativity Research Journal*, *22*(3), 329–
578 336. https://doi.org/10.1080/10400419.2010.503543
579 Lillard, A., & Else-Quest, N. (2006). Evaluating Montessori education. *Science*, *313*(5795),
580 1893–1894. https://doi.org/10.1126/science.1132362
581 Lillard, A., Heise, M. J., Richey, E. M., Tong, X., Hart, A., & Bray, P. M. (2017). Montessori
582 preschool elevates and equalizes child outcomes: A longitudinal study. *Frontiers in*
583 *Psychology*, *8*, 1783. https://doi.org/10.3389/fpsyg.2017.01783

584 Lubart, T., Besançon, M., & Barbot, B. (2011). *EPoC: Evaluation du potentiel créatif des*
585 *enfants* (Hogrefe).
586 Marshall, C. (2017). Montessori education: a review of the evidence base. *Science of*
587 *Learning*, *2*(1), 1–9. https://doi.org/10.1038/s41539-017-0012-7
588 Miller, B. C., & Gerard, D. (1979). Family Influences on the Development of Creativity in
589 Children: An Integrative Review. *The Family Coordinator*, *28*(3), 295–312.
590 https://doi.org/10.2307/581942
591 Montessori, M. (1936). *The Secret Of Childhood*. Carter,barbara Barclay Ed.
592 https://archive.org/details/in.ernet.dli.2015.443380/page/n9/mode/2up
593 Mouchiroud, C., & Lubart, T. (2016). Social creativity: A cross-sectional study of 6- to 11-
594 year-old children. *International Journal of Behavioral Development*, *26*(1), 60–69.
595 https://doi.org/10.1177/016502540202600111
596 Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing Cognitive Control: Three
597 Key Transitions. *Current Directions in Psychological Science*, *21*(2), 71.
598 https://doi.org/10.1177/0963721412436807
599 Paulus, P. B., & Dzindolet, M. (2008). Social influence, creativity and innovation. *Social*
600 *Influence*, *3*(4), 228–247. https://doi.org/10.1080/15534510802341082
601 Piaget, J. (1952). *The origins of intelligence in children*. W W Norton & Co.
602 https://doi.org/10.1037/11494-000
603 Piaget, J. (1954). The development of object concept. *The Construction of Reality in the*
604 *Child.*, 3–96. https://doi.org/10.1037/11168-001
605 Piaw, C. Y. (2014). Effects of Gender and Thinking Style on Student's Creative Thinking
606 Ability. *Procedia - Social and Behavioral Sciences*, *116*, 5135–5139.
607 https://doi.org/10.1016/J.SBSPRO.2014.01.1087
608 Plucker, J. A., & Renzulli, J. S. (1999). Psychometric Approaches to the Study of Human

Creativity. *Handbook of Creativity*, 35–61. https://doi.org/10.1017/cbo9780511807916.005

R Studio Team. (2020). *RStudio: Integrated Development for R*. http://www.rstudio.com/.

Raina, M. K., Kumar, G., & Raina, V. K. (1980). A cross-cultural study of parental perception of the ideal child. *Creative Child & Adult Quarterly*, *5(4)*, 234–241.

Rawlings, B., & Legare, C. H. (2021). Toddlers, Tools, and Tech: The Cognitive Ontogenesis of Innovation. *Trends in Cognitive Sciences*, *25*(1), 81–92. https://doi.org/10.1016/J.TICS.2020.10.006

Runco, M. A., & Acar, S. (2019). Divergent Thinking. *The Cambridge Handbook of Creativity*, 224–254. https://doi.org/10.1017/9781316979839.013

Saggar, M., Xie, H., Beaty, R. E., Stankov, A. D., Schreier, M., & Reiss, A. L. (2019). Creativity slumps and bumps: Examining the neurobehavioral basis of creativity development during middle childhood. *NeuroImage*, *196*, 94–101. https://doi.org/10.1016/J.NEUROIMAGE.2019.03.080

Said-Metwaly, S., Fernández-Castilla, B., Kyndt, E., Van den Noortgate, W., & Barbot, B. (2021). Does the Fourth-Grade Slump in Creativity Actually Exist? A Meta-analysis of the Development of Divergent Thinking in School-Age Children and Adolescents. *Educational Psychology Review*, *33*(1), 275–298. https://doi.org/10.1007/S10648-020-09547-9/TABLES/2

Sak, U., & Maker, C. J. (2006). Developmental variation in children's creative mathematical thinking as a function of schooling, age, and knowledge. *Creativity Research Journal*, *18*(3), 279–291. https://doi.org/10.1207/S15326934CRJ1803_5

Sauzéon, H., Lestage, P., Raboutet, C., N'Kaoua, B., & Claverie, B. (2004). Verbal fluency output in children aged 7-16 as a function of the production criterion: qualitative analysis of clustering, switching processes, and semantic network exploitation. *Brain and*

Language, *89*(1), 192–202. https://doi.org/10.1016/S0093-934X(03)00367-5

Shao, Y., Zhang, C., Zhou, J., Gu, T., & Yuan, Y. (2019). How does culture shape creativity? A mini-review. *Frontiers in Psychology*, *10*(MAY), 1219. https://doi.org/10.3389/FPSYG.2019.01219/BIBTEX

Snyder, H. R., & Munakata, Y. (2010). Becoming self-directed: Abstract representations support endogenous Flexibility in children. *Cognition*, *116*(2), 155–167. https://doi.org/10.1016/J.COGNITION.2010.04.007

Snyder, H. R., & Munakata, Y. (2013). So many options, so little control: abstract representations can reduce selection demands to increase children's self-directed flexibility. *Journal of Experimental Child Psychology*, *116*(3), 659–673. https://doi.org/10.1016/J.JECP.2013.07.010

Sternberg, R. J., & Lubart, T. I. (1996). Investing in Creativity. *American Psychologist*, *51*(7), 677–688. https://doi.org/10.1037/0003-066X.51.7.677

Stevenson, C. E., Kleibeuker, S. W., de Dreu, C. K. W., & Crone, E. A. (2014). Training creative cognition: Adolescence as a flexible period for improving creativity. *Frontiers in Human Neuroscience*, *8*, 827. https://doi.org/10.3389/FNHUM.2014.00827/BIBTEX

Timmel, J. L. (2001). *Creativity and acculturation: Psychological and cultural effects on the divergent thinking of cuban preadolescent immigrants entering the united states*. https://www.proquest.com/dissertations-theses/creativity-acculturation-psychological-cultural/docview/304690410/se-2?accountid=12006

Torrance, E. P. (1968). A Longitudinal Examination of the Fourth Grade Slump in Creativity. *Gifted Child Quarterly*, *12*(4), 195–199. https://doi.org/10.1177/001698626801200401