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Divergent thinking and Executive functions in children: A developmental perspective based on intellectual capacity

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A B S T R A C T

Despite the importance of Executive functions, Divergent thinking, and intelligence in 21st century society, few studies have analyzed these variables in childhood and adolescence. The present study aimed to examine whether Executive functions and Divergent thinking have a developmental perspective and whether these variables predict intelligence. A non-clinical sample of 159 adolescents (78 girls and 81 boys) between 12 and 16 years of age (M=13.29 years; SD=1.17) participated in the study. Three tests were administered: (1) the Ice cream Virtual Reality Test to measure Executive functions; (2) the PIC-J to evaluate Divergent thinking; and (3) the WISC-V to measure cognitive variables. Executive functions were found to be developmental, as was verbal fluency as a creative component. However, only the Executive functions predicted intelligence. These findings provide information about how Executive functions develop and may contribute to helping develop students' talents. They also highlight the importance of learning more about Divergent thinking.

1. Introduction

Creativity is a dynamic cognitive process which includes the ability to generate new ideas or make new connections between existing ideas in order to adapt responses to different situations and develop innovative solutions (Guilford, 1967; Sternberg, 2020). Rooted in a combination of originality and practical value, creativity is a multifaceted construct that is vital for problem-solving and progress (Runco & Jagger, 2012).

The fundamental components of creativity are Divergent thinking (DT) and Convergent thinking (CT), characterized as pivotal processes of creative potential (Zhang et al., 2020). DT is recognized as a fundamental cognitive process that facilitates the generation of diverse sets of ideas. It operates by encouraging cognitive flexibility, breaking away from conventional thought patterns, and promoting the exploration of a wide range of potential solutions to open-ended problems (de Vries & Lubart, 2019; Goldschmidt, 2016). CT involves systematic evaluation of and convergence towards well-defined, optimal solutions from the pool of ideas produced during the divergent phase (de Vries & Lubart, 2019; Goldschmidt, 2016).

In the context of a process-oriented approach, creativity is often measured by tests based on components of DT, which is considered a key facet of creative potential and an integral step in the overall creative process (Lubart et al., 2013; Runco & Acar, 2012). These tests generally focus on four indicators: fluency, flexibility, originality and elaboration (Guilford, 1967; Runco & Acar, 2012). More

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specifically, flexibility refers to the capacity to create a varied range of distinctly different concepts, while fluency concerns the number of ideas produced. Originality is about on the uniqueness of concepts generated, and elaboration involves the ability to comprehensively expand and develop these concepts (Handayani et al., 2021; Hendrik et al., 2022).

Furthermore, DT can be assessed either through verbal or figurative production (Goff & Torrance, 2002). Figural DT can be assessed using drawing tasks, such as the Torrance Test of Creative Thinking-Figural (TTCT; Torrance, 1998) or the Test for Creative Thinking-Drawing Production (TCT-DP; Jellen & Urban, 1986). Verbal DT can be assessed in terms of fluency, flexibility, and narrative and verbal originality, for instance by using the Alternative Uses Task (AUT; Guilford, 1967; Guilford et al., 1978).

It is important to bear in mind that DT is expressed in different ways at each stage of development. Adolescents manifest DT differently to children or adults (Woodel-Johnson et al., 2012). In fact, various authors have stated that DT improves with age (Alacapinar, 2013; Hong & Milgram, 2010) and have found that creativity, in general terms, increases significantly throughout schooling, although originality may decrease between 10 and 14 years of age (Claxton et al., 2005; Sali, 2015). On the other hand, Kleibeuker et al. (2016) argued that fluency and flexibility are fully developed in adolescence, but the quality of solutions and originality continue to develop into adulthood, with differences in the different components. Therefore, understanding the cognitive development of this variable is crucial (Vaisarova & Carlson, 2021).

Creativity can present different forms. In this regard, the creative cognition approach argues for the involvement of different cognitive processes within the creative process (Ferrándiz et al., 2017; Ward, 2007). Considering the complex nature of DT, one of the cognitive processes that could play an important role is Executive functions (EF) (Benedek & Fink, 2019). EF are the cognitive capacities for effective, creative, socially accepted behavior (Lezak, 1982). They are also defined as the cognitive abilities that allow human beings to control and coordinate their goal-directed behaviors and thoughts (Carlson et al., 2013).

Various models have been proposed to describe EF. A review of the different models of EF (Tirapu et al., 2018) concluded that working memory, inhibition, shifting, verbal fluency and planning are the most commonly-found executive processes in the factorial models of EF in children and adolescents. More specifically, the processes of working memory and inhibition are present from an early age and are strongly correlated with each other—supporting a single factor structure that progressively diversifies with age—whereas shifting and verbal fluency processes emerge at school age, and planning appears towards pre-adolescence.

Along these lines, Miyake et al. (2000) presented a model by using multiple tasks to measure each component of EF and adopting a Latent Variable approach to extract the variance common to these tasks, assuming that by using multiple tasks, the factor common to these tasks would be a purer measure of EF. The main components related to EF are: inhibition, working memory, and shifting (Diamond, 2013; Lehto et al., 2003; Miyake et al., 2000). In our study, these components were selected rather than others because they are relatively simple to analyze and operationalize and, although clearly distinct, share underlying commonalities, as well as being related to other EFs such as planning, attention, switching and problem solving (Diamond, 2013; Miyake et al., 2000). However, this latent variable approach also has significant limitations related to the subjective interpretation of the latent factors, since the decision of how to define the latent factors lies with the researchers (Rosales et al., 2023).

Currently, there is an alternative approach called Network Models which does not involve researchers determining latent factors and is not constrained by the principle of local independence (Kan et al., 2019). However, it also has notable limitations because it only fits well if the covariance between variables is large and when measurement error is small. Because of that, several researchers have opted for latent variable models over network models (Rosales et al., 2023).

The development of EF starts from the first year of life and continues to the end of adolescence and should be considered as different points in the maturation process (Cassandra & Reynolds, 2005). Authors such as Filippetti (2011) found that there might be a different pattern of development for the different executive domains: planning, working memory inhibition, verbal fluency and shifting. For example, working memory seems to follow a gradual course of development that begins in early childhood and continues through adolescence, shifting reaches adult-level performance at early ages of development, and planning ability remains relatively stable between the ages of 7 and 12.

Although studies such as Huizinga et al. (2006) maintained that the development of working memory continues into early adulthood, cognitive flexibility has been shown to gradually develop during middle childhood, continuing until adolescence. Finally, full development of planning is achieved in adolescence.

Proper development of EF is essential for the proper development of creativity. This means that successful performance of EF plays a crucial role in the production of innovative ideas, DT, and flexible adaptation, which are fundamental components of creativity (Krumm et al., 2018). In this regard, although there might be a clear connection between EF and DT in children and adolescents, different studies have produced varied results (Crenshaw & Miller, 2022; Palmiero et al., 2022). Shifting has been positively correlated with creativity, while inhibition has been negatively correlated (Pasarín-Lavín et al., 2023). Cognitive training programs that target working memory have shown beneficial effects on measures of DT, suggesting the possibility of a relationship in which working on one improves the other (Orzechowski et al., 2023). Additionally, Wang et al. (2021) indicated that EF such as inhibition and shifting were related to DT.

Furthermore, looking at variable predictiveness the outcomes are inconclusive. Authors such as Zabelina et al. (2019) indicated that EF, such as working memory and inhibition, predicted creativity depending on how creativity is defined: as DT or creative performance. Benedek et al. (2014) also found that updating and inhibition predicted creativity measured with 4 DT tasks.

These findings suggest that DT and EF contribute to each other's development. However, it is important to note that the relationship between creativity and EF might be influenced by other components such as intelligence (Ardila, 2018). This relationship is still unclear and requires further investigation.

Krumm et al. (2018) indicated that there was evidence of a relationship between intelligence (fluid and crystallized), EF, and DT. Intelligence has been defined in various ways; in the development of intelligence scales, Wechsler (2014) identified a multiple

Table 1
Demographic characteristics of the sample.

Groups		Gender		Age		FSIQ		VCI		FRI	
	n	*M*	*F*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1st year	55	26	29	12.15	.488	101.49	11.60	104.83	12.67	97.26	13.16
2nd year	58	27	31	13.16	365	101.20	11.02	105.76	12.47	94.67	15.60
3rd year	13	7	6	14.08	.277	107.08	11.13	113.77	7.40	104.61	12.29
4th year	33	21	12	15.12	.331	102.99	12.92	107.90	14.54	98.19	12.06
Total	159	81	78	13.29	1.17	102.15	11.65	106.80	12.80	97.11	13.96

Note. FSIQ = Full Scale IQ; VCI = Verbal Comprehension Index; FRI = Fluid Reasoning Index; M = Mean; SD = Standard deviation

intelligence component (Full Scale IQ). This was divided into five indexes, with the Verbal Comprehension Index (VCI) and the Fluid Reasoning Index (FRI) best reflecting the importance of fluid and crystallized capacities in this model.

In terms of the relationship between intelligence and EF, authors such as Benedek et al. (2014) reported that fluid intelligence was strongly predicted by EF such as working memory, but not by inhibition or shifting. This might be explained by the fact that, since intelligence is a multidimensional construct, intelligence tests might take advantage of other mental abilities such as working memory, processing speed, or attention (Arffa, 2007).

In contrast, Plucker and Esping (2015) outlined several perspectives on the relationship between DT and intelligence: (1) DT as a facet of intelligence; (2) DT as a result of intelligence, or (3) DT as a separate construct, sharing cognitive abilities with intelligence. Later, Plucker et al. (2020) suggested that intelligence and DT may be related but there are still no studies that fully demonstrate that. Other authors—such as Pan and Yu (2018), with a sample of 109 undergraduate students—have shown that intelligence has a positive relationship with originality as an element of DT. In addition, Silvia (2015) asserted that people who scored highly in intelligence tests also scored highly in creativity tasks, specifically DT tasks, and concluded that as current cognitive neuroscience suggests, DT and intelligence are linked although there is no real scientific evidence.

The relationship between intelligence and EF seems clearer, since intelligence tests usually involve different EF (Areces et al., 2018). In addition, some studies have focused on analyzing the relationship between VR-based Continuous Performance tests and Wechsler intelligence scale components (Areces et al., 2018; Krch et al., 2013). Along these lines, Areces et al. (2018) showed that students with EF deficits had lower scores in working memory and processing speed, as well as exhibiting poorer performance in EF assessed via VR in comparison to their peers without EF difficulties.

On the other hand, the relationship between intelligence and DT is not so clear since there are very few empirical studies, and what has been reported is sometimes contradictory (Plucker & Esping, 2015; Silvia, 2015, Vaisarova & Carlson, 2021). However, it is interesting to analyze whether DT also predicts intelligence, looking at creativity as an emerging and less researched construct in this field. For example, Frith et al. (2021) focused on executive capacity as a mediator between fluid intelligence and creative potential measured as DT, considering inhibition and working memory.

However, the development of DT and EF in childhood and adolescence, as well as their interrelation with other factors like intelligence, is important for appropriate educational interventions. Studies in this field should also consider how these components develop over time, adopting developmental perspectives.

Interest in the variables in the present study is due to how important they are in today's society, and this means that they need to be thoroughly understood from childhood onwards. However, there are as yet few studies that have looked at this relationship in children or adolescents (Benedek et al., 2014; Bernabeu-Brotons et al., 2021; Pan & Yu, 2018). In addition, as both DT and EF develop during childhood and adolescence, and may have a different relationship than in adults (Krumm et al., 2020). Finally, using a VR-based tool to measure EF might provide ecological validity to the research while offering an innovative approach to the study of this relationship.

2. The present study

The present study examines the relationships between EF, creativity (assessed with two measures of DT) and intelligence, aiming to show the developmental character of EF and creativity and how predictive they are of intelligence. This overall goal includes two specific objectives:

O1. Analyze EF and creativity considering a developmental perspective.
O2. Analyze the predictive nature of EF and creativity in intelligence.

Based on previous research (Cassandra & Reynolds, 2005; Kaufman & Beghetto, 2009), EF and creativity will probably improve as children move up through school years, in other words, these variables are developmental. Similarly, as Plucker et al. (2020) and Ardila (2018) suggested, EF and creativity are expected to predict intelligence.

3. Method

3.1. Participants

The initial sample consisted of 182 high school students. Based on the data provided by the school, the inclusion criteria included: (1) children without special needs; (2) in the 1^{st} to 4^{th} year of secondary education; (3) who attend school regularly. Based on these criteria, 23 students with SEN were excluded from the sample. The final sample consisted of 159 secondary-school students from the north of Spain (78 girls and 81 boys; $M = 13.29$ years; $SD = 1.17$ years; range from 12 to 16 years). The sample was split into four groups based on the school year: 1^{st} year ($n = 55$); 2^{nd} year ($n = 58$); 3^{rd} year ($n = 13$); 4^{th} year ($n = 33$). Following an intelligence assessment, 62.3% demonstrated an average IQ (90-109), 15.7% a high average IQ (110-119), 10.1% a very high IQ (120-129); 8.2% a low average IQ (80-89); and 3.8% a very low IQ (70-79). Table 1 shows the demographic characteristics of the sample. There were no significant differences between IQ ($p = .512$) or gender (x^2 =,057; df = 1; $p = .812$).

3.2. Instruments and measures

3.2.1. Measures of Executive functions

Nesplora Executive Functions - Ice Cream measures various components of EF and learning in children from 8 years old through an immersive experience with VR.

The test is a 20-45 minute recreation of a realistic multitasking environment based on the premise "it's your first day at work in an ice cream shop". Various rules must be followed and objectives met in order to complete the challenges presented. The ecological validity of this test allows EF to be measured, maximizing the predictive value of the real functional performance of the person being evaluated. *Nesplora Executive functions - Ice Cream* has some special features that make it seem more like an "adaptive" test, therefore it has very good ecological validity, but in addition, all the main test variables show reliability via McDonald's Omega coefficients of between .85 and .97 (Fernandez et al., 2023).

The test measures the EFs *planning, working memory, processing speed* and *cognitive flexibility*. Miyake's model is mentioned above as a basic theoretical model, but inhibition was not included as a measurement variable because of the characteristics of the test.

3.2.2. Measures of Divergent thinking

PIC-J. Prueba de Imaginación Creativa para Jóvenes- Creative Imagination Test for Young People (Artola et al. 2008) is a test to evaluate creativity, measured as DT, in subjects between 12 and 18 years old through their use of imagination. It consists of four games: three assess verbal or narrative creativity, while the fourth assesses graphic creativity. Game 2 and game 4 were used for the study. Game 2 involves a test of possible uses of an object to assess *Verbal Fluency, Verbal Flexibility* and *Verbal Originality*. Game 4 uses a graphical imagination test inspired by the Torrance Test of Creative Thinking (TTCT; Torrance, 1998) to assess *Figural creativity* based on the dimensions of *Originality* and *Elaboration*. It includes the variables *Title* and *Graphic Details*. The test's psychometric properties and reliability were checked by the authors, giving a Cronbach's Alpha for the test set of .85

PIC-J Interrater Agreement. One of the most significant problems in creativity tests is the difficulty for two raters to produce equivalent scores. For this reason, interrater agreement was used to check the validation of the scoring of the PIC-J. The degree of agreement was calculated using Cohen's weighted kappa statistic (k). Landis and Koch (1977) suggested an interpretation as follows: values ≤ 0 as poor; 0.00 – 0.20 as slight, 0.21 – 0.40 as fair, 0.41 – 0.60 as moderate, 0.61 – 0.80 as substantial, and 0.81–1.00 as almost perfect agreement.

Implementing Cohen's Kappa involved the following considerations: (1) there are two raters who analyze at least 25% of the sample; (2) they have the same instructions and criteria for rating; and (3) the items to be rated are independent.

In the initial comparison, the k value was slight in several variables, with the highest values in *Verbal Fluency (*substantial, > 0.61), *Verbal Flexibility* (moderate, > 0.41) and *Graphic Details* (moderate, > 0.41). Twenty more subjects were evaluated after discussion and agreement between raters, producing k values that were almost perfect (*Verbal Fluency* and *Figural Elaboration*, > 0.81) and substantial (*Verbal Flexibility, Verbal Originality, Figural Originality, Figural Title and Graphic Details*, > 0.61).

3.2.3. Measures of Intelligence

The Spanish adaptation of the WISC-V (Wechsler, 2014) was used in this study. The internal consistency of the Spanish adaptation of the WISC-V has been examined using the two-half method. The reliability of the IQ (FSIQ) is 0.95 (Amador & Forns, 2019)

In this study, the 7 main measurements used to obtain *Full Scale IQ (FSIQ)* were: Similarities and Vocabulary for Verbal Comprehension; Block Design for Visual Spatial; Matrix Reasoning and Weights for Fluid Reasoning; Digit Span for Working Memory; and Symbol Research for Processing Speed. These measures produced the *Verbal Comprehension Index* (VCI) and the *Fluid Reasoning Index* (FRI),

3.3. Procedure

The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki), which reflects the ethical principles for research involving humans (World Medical Association, 2013). The study was approved by the Ethics Committee of the Principality of Asturias (reference: CEISH-UPV/EHU, BOPV 32) and all procedures were in compliance with relevant laws and institutional guidelines. Data were collected from children, schools and parents.

Table 2
Descriptive statistics.

Variables	Total (n = 159)	Secondary school year			
		1st year (n = 55)	2nd year (n = 58)	3rd year (n = 13)	4th year (n = 33)
DT					
Verbal fluency					
M (SD)	8.89 (4.93)	7.44 (5.08)	9.59 (4.52)	9.46 (4.79)	9.85 (5.06)
Kurtosis	1.39	6.10	-.708	3.31	-.023
Skewness	1.03	2.08	.290	1.78	-619
Verbal flexibility					
M (SD)	6.37 (2.85)	5.25 (2.77)	6.91 (2.72)	7.39 (2.81)	6.89 (2.76)
Kurtosis	-.504	1.13	-.728	-.028	-.571
Skewness	.227	.915	-.192	.859	-.130
Verbal originality					
M (SD)	7.17 (5.14)	5.50 (4.57)	7.93 (5.18)	8.46 (4.43)	8.11 (5.70)
Kurtosis	.691	2.08	-.250	.612	1.41
Skewness	1.07	1.43	.196	1.23	1.20
Figural originality					
M (SD)	4.78 (2.41)	4.37 (2.37)	5.09 (2.27)	5.46 (2.88)	4.66 (2.48)
Kurtosis	-.445	-.348	-.250	-.797	-.610
Skewness	.265	.362	.196	.445	.132
Figural elaboration					
M (SD)	.884 (1.27)	.831 (1.08)	.88 (1.31)	.846 (1.41)	.996 (1.46)
Kurtosis	4.48	.397	6.96	6.79	3.60
Skewness	1.88	1.17	2.16	2.45	1.88
Figural title					
M (SD)	1.67 (1.80)	1.62 (1.70)	1.35 (1.56)	3.46 (2.57)	1.62 (1.69)
Kurtosis	.145	.257	.668	-1.52	.205
Skewness	.975	.883	1.17	-.226	.929
Graphic details					
M (SD)	.443 (.731)	.362 (.641)	.397 (.699)	.846 (1.07)	.499 (.750)
Kurtosis	1.95	4.83	.787	-.705	2.78
Skewness	1.63	2.07	1.59	.838	1.66
EF					
Planning					
M (SD)	10.15 (3.82)	8.37 (3.92)	11.07 (3.15)	11.39 (2.96)	11.007 (4.10)
Kurtosis	-.675	-1.36	1.56	-.706	.237
Skewness	-.810	-.071	-1.49	-.924	-1.31
Working Memory					
M (SD)	46.83 (6.83)	45.49 (6.38)	46.23 (7.22)	47.46 (9.40)	49.85 (4.72)
Kurtosis	.352	-.557	-.091	2.41	1.11
Skewness	-.878	-.460	-.743	-1.69	-.926
Flexibility Interference					
M (SD)	14.06 (19.35)	15.75 (21.53)	13.77 (17.79)	23.00 (27.17)	8.20 (12.41)
Kurtosis	3.95	3.74	3.03	2.14	-.559
Skewness	1.61	1.47	1.42	1.50	.757
Flexibility Perseverance					
M (SD)	1.25 (1.80)	1.36 (1.79)	1.42 (2.01)	1.46 (2.18)	.693 (1.06)
Kurtosis	5.05	8.18	2.77	2.29	4.04
Skewness	2.14	2.55	1.78	1.62	1.97

Note. EF = Executive functions; DT = Divergent thinking; M = Mean; SD = Standard deviation.

All parents received notice requesting informed consent which described the aims of the study and had to be signed before the study began.

EF was assessed by a psychologist specializing in using the tool, in groups of 5 students due to the nature of the test—an immersive experience with VR. Assessment of DT and intelligence was performed individually by four specialists in educational psychology from the University of Oviedo who had been previously trained in the use of the tests. The professionals underwent two training sessions. The initial session introduced participants to the WISC-V and PIC-J tests, as well as ethical considerations for applying them. The second session provided opportunities to practice applying the concepts and interpreting the results.

The tests were carried out over two weeks in each school, with a maximum of one day between the two tests for each student.

The students were naturally organized by school year and the sampling was by accessibility. Participants did not receive any reinforcement/rewards for participation. The order of the tests was randomized in the sample, one part of the group did the intelligence and DT test first and the other part of the group did the EF test and vice versa. The total evaluation for each subject lasted two and a half hours split into two sessions.

Table 3
Pearson Correlations for Executive functions and Divergent thinking variables.

	1	2	3	4	5	6	7	8	9	10	11
1.VFLU	—										
2. VFLE	.31**	—									
3.VOR	.15*	.11	—								
4.FOR	.20**	.28**	.11	—							
5.FEL	.23**	.06	.25**	.19**	—						
6.FTIT	.14*	-.15*	.16*	.08	.79**	—					
7.GDET	.04	.05	.21**	.05	.66**	.37**	—				
8.PLAN	.31**	.32**	.25**	.30**	.74**	.41**	.26**	—			
9.WM	.03	-.17*	.02	.01	.49**	.37**	.31**	.15*	—		
10.FINT	-.06	.17*	.03	.06	-.36**	-.37**	-.17*	-.22**	-.28**	—	
11. FPER	-.09	.18**	.10	.04	-.27**	-.33**	-.08	-.14*	-.27**	.78**	—

Note. VFLU = Verbal Fluency; VLE = Verbal Flexibility; VOR = Verbal Originality; FOR = Figural Originality; FEL = Figural Elaboration; FTIT = Figural Title; GDET = Graphic Details; PLAN = Planning; WM = Working Memory; FINT = Flexibility Interference; FPER = Flexibility Perseverance *$p < .05$; **$p < .01$.

3.4. *Data analysis*

Statistical analyses were performed using SPSS 27.0. First, descriptive statistics for the variables were calculated (see Table 2) and the indicators of sample normality (kurtosis and skewness) were examined. The effect of gender and intelligence on the dependent variables was assessed. Subsequently, parametric analysis was performed via analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) to determine the developmental perspective of EF and DT. Differences were considered as statistically significant at a level of $p \leq 0.05$. In order to identify the differences between the groups, *Sheffé* multiple comparisons were used. Effect sizes were calculated using *partial eta squared* (η_p^2) following *Cohen's d* criteria (1988).

Finally, hierarchical regression analysis was conducted to predict the influence of those variables on intelligence. The first model included the effect of age and gender, the second model added EF variables, while the third model added DT variables.

4. Results

4.1. *Initial analysis*

Considering Finney and DiStefano (2006), the values for *skewness* and *kurtosis* indicated that all of the data were normally distributed (see Table 2), hence the data were analyzed through parametric analysis.

As Table 3 shows, there was significant correlation between most of the variables. In some cases, this correlation was not positive, such as *figural originality* with almost all variables (except figural elaboration and planning), and *verbal originality* with *figural elaboration* and *graphic details*, among others.

4.2. *Executive functions and Divergent thinking*

MANOVA analysis with gender indicated that there were no statistically significant differences for divergent thinking ($p = .563$) or EF ($p = .160$) variables according to gender.

Secondly, MANOVA analysis with year groups showed statistically significant differences for DT ($\lambda = .765$; $F(3,158) = 1.992$; $p < .001$; $\eta p^2 = .085$) and for EF ($\lambda = .807$; $F(3,158) = 2.824$; $p < .001$; $\eta p^2 = .069$).

Inter-subject effects indicated statistically significant differences between year groups in the EF variables *planning* ($F(3,158) = 6.781$; $p < .001$; $\eta p^2 = .116$), and *working memory* ($F(3,158) = 3{,}162$; $p = .026$; $\eta p^2 = 0.58$), and the DT variables *verbal flexibility* ($F(3,158) = 4{,}806$; $p = .003$; $\eta p^2 = 0.85$), *verbal originality* ($F(3,158) = 3{,}118$; $p = .028$; $\eta p^2 = 0.57$), and *graphic title* ($F(3,158) = 5{,}325$; $p = .002$; $\eta p^2 = 0.93$).

A deeper analysis of the development of EF and DT considering the groups using the Scheffé *post-hoc* test with different variables showed that there were differences between 1st, 2nd and 4th years in *planning* ($p = .003$); between 1st and 4th years in *working memory* ($p = .017$); and between 1st and 2nd years in *verbal flexibility* ($p = .018$).

Finally, interactions between gender and year group also indicated no statistically significant differences for DT ($p = .625$) or EF ($p = .124$) variables by group.

4.3. *Involvement of Executive functions and Divergent thinking in intelligence*

A hierarchical regression analysis was performed to predict the influence of EF and creativity on intelligence, considering intelligence as a general scale (FSIQ) and its two indexes of *verbal comprehension* (CVI) and *fluent reasoning* (RFI).

FSIQ regression showed that model 2 gave the highest percentage of explained variance, when the model included EF, with *working memory* and *interference flexibility* being significant.

Similarly, CVI regression indicated that models 2 and 3 were significant when the model included EF, with gender and *planning* being significant. Subsequently adding the DT variables increased the explained variance with gender, *planning* and *figural title* being significant.

Finally, FRI regression demonstrated that none of the models was significant, although some specific variables were (e.g. *flexibility interference* in model 2 and model 3).

5. Discussion

5.1. Developmental perspective of Executive functions and Divergent thinking

The results suggest that EF such as planning and working memory are developmental. More specifically, there was an increase in scores from 1st year to 4th year. This is consistent with Davidson et al. (2006), who noted that until the age of 19, EF such as cognitive flexibility may not be fully developed. However, it contradicts Filippetti (2011), who indicated that cognitive flexibility, working memory and verbal fluency develop with age but planning does not. This may be because different age ranges were evaluated, but not many studies have looked at this progression, perhaps because of the relationship between WISC-V and EF variables, seeing as how all of the WISC-V subtests evaluate some of these (planning, working memory, processing speed, etc.).

There was a different result for DT, with levels of verbal variables such as verbal DT, verbal originality, and graphic title being maintained. However, figural DT demonstrated a downward trend as schooling progressed. This contradicts the results from Hong and Milgram. (2010), noting the development of creativity, measured as DT, throughout children's development. This may be because adolescents have developed verbal fluency, but the quality of their responses continue to improve as they learn new knowledge, skills, and aptitudes. Adolescents can make associations, but it is a skill that is fully developed in late adolescence (Kleibeuker et al., 2016).

Creative processes are expressed in different ways in each of the developmental stages, with adolescents expressing creativity differently from children or adults (Woodel-Johnson et al., 2012). This is why there were clear differences between 12-year-old students and 16-year-old students and why there are no studies that demonstrate a clear interrelationship between age and creativity (Revuelta et al., 2022).

5.2. Predictive value of variables related to Executive functions and Divergent thinking on intelligence

As previous studies have reported, EF had a clear predictive relationship with intelligence. In particular, cognitive flexibility and working memory are more clearly consistent with Ardila (2018) and Benedek et al. (2014). Arya and Maurya (2016) stated that this may be because schools today contribute to the development of intelligence but hardly at all to creativity.

In contrast, DT could not be shown to predict intelligence. These results are consistent with Silvia (2015) who found no evidence for it. A nonlinear relationship between DT and cognitive abilities, such as intelligence, was asserted by some early theorists (e.g. Guilford, 1967). Creativity, despite being a necessary skill for 21st century education, is still an open, controversial field (Runco, 2014).

Researchers such as Plucker et al. (2020) believed that intelligence and DT may be related but there are still no studies that fully demonstrate this. For example, Pan and Yu (2018) analyzed a sample of 109 undergraduate students and showed that intelligence had a positive relationship with originality as an element of DT. Following a study with 242 students between the ages of 18 and 19, Silvia (2008) noted that previous research had likely underestimated the DT-intelligence relationship. Along similar lines, Silvia (2015) noted that people who scored highly in intelligence tests also scored highly in creative tasks—measured as DT—and concluded that current cognitive neuroscience implies that creativity and intelligence are linked although there is no real scientific evidence.

When EF variables were included, the regression model was significant and therefore predicted intelligence. These results are consistent with Ardila (2018) and Benedek et al., (2014) indicating that that some EF correspond to intelligence, especially the more intellectual functions such as working memory, planning, and attention.

On the other hand, the model was only significant in the verbal comprehension index when DT variables were included. This is consistent with Benedek et al. (2014), who noted that the relationship between DT and intelligence had to do with EF and verbal fluency. According to Amunts et al. (2020), verbal fluency could be considered a component of EF, or at least be strongly related. These results show that EF development can help the creative process, especially at the verbal level of DT, during the evaluation phase (Beaty et al., 2014, Krumm et al., 2018).

6. Conclusions and Limitations

Understanding the relationship between DT, EF, intelligence, and learning requires combined contributions from neuropsychology and education. In this regard, one of the main practical implications of this study for education is that it indicates that the development of these skills should be promoted at school since they have a direct relationship with intellectual ability. Promoting EF at school could help produce more talented students, with greater verbal intelligence and fluid reasoning, and could therefore make them more creative.

As for creativity, it is important to consider it a construct yet to be discovered and, because of the variability and subjectivity of the evaluation tests, no real conclusions can be reached. In this regard, our study is a small contribution that can help us understand how important variables like DT are related at the educational level.

However, the study does have some limitations that must be considered in future research. The sample size of some of the groups may limit the generalizability of the results. It might be interesting to add a sample of students with special educational needs (SEN) to compare the progression in these variables in students with different needs.

Table 4
Divergent thinking and Executive functions descriptive statistics by gender and year groups.

	TOTAL		1st year		2nd year		3rd year		4th year	
	M	F	M	F	M	F	M	F	M	F
DT										
VFLU	9.48 (5.18)	8.27 (4.60)	7.93 (5.47)	7.00 (4.77)	10.52 (4.71)	8.77 (4.26)	11.57 (5.56)	7.00 (2.10)	9.38 (5.05)	10.68 (5.17)
VFLE	6.71 (2.81)	6.02 (2.86)	5.60 (2.72)	4.93 (2.81)	7.33 (2.50)	6.55 (2.90)	8.43 (2.88)	6.17 (2.40)	6.71 (2.94)	7.21 (2.50)
VOR	7.66 (5.18)	6.66 (5.08)	5.87 (4.98)	5.17 (4.23)	8.85 (5.30)	7.13 (5.02)	9.86 (5.21)	6.83 (2.93)	7.62 (4.89)	8.97 (7.05)
FOR	4.88 (2.36)	4.68 (2.46)	4.71 (2.14)	4.07 (2.55)	4.93 (2.50)	5.23 (2.09)	5.29 (3.25)	5.67 (2.66)	4.91 (2.28)	4.23 (2.86)
FEL	.959 (1.37)	.806 (1.15)	.950 (1.22)	.724 (.960)	.963 (1.63)	.806 (.981)	1.43 (1.72)	.167 (.408)	.810 (1.12)	1.32 (1.93)
FTIT	1.60 (1.68)	1.75 (1.93)	1.62 (1.35)	1.62 (1.99)	1.15 (1.26)	1.52 (1.79)	4.00 (2.71)	2.83 (2.48)	1.33 (1.56)	2.13 (1.86)
GDET	.468 (.772)	.416 (.690)	.420 (.796)	.310 (.471)	.370 (688)	.419 (.720)	1.28 (1.25)	.333 (.516)	.381 (.498)	.706 (1.05)
EF										
PLAN	10.29 (3.77)	9.99 (3.89)	8.77 (3.59)	8.00 (4.22)	11.57 (3.04)	10.63 (3.24)	10.57 (3.74)	12.33 (1.51)	10.43 (4.39)	12.02 (3.48)
WM	46.40 (7.43)	47.26 (6.16)	43.83 (6.30)	46.98 (6.18)	46.49 (8.70)	46.01 (5.77)	45.14 (10.14)	50.17 (8.52)	49.91 (4.45)	49.74 (5.36)
FINT	15.38 (21.67)	12.68 (16.64)	21.30 (26.61)	10.78 (14.41)	10.82 (14.21)	16.34 (20.28)	37.00 (30.40)	6.67 (8.21)	6.71 (11.75)	10.79 (13.62)
FPER	1.47 (2.11)	1.03 (1.38)	1.86 (2.32)	.911 (.944)	1.42 (2.29)	1.43 (1.77)	2.57 (2.51)	.167 (.408)	.667 (1.02)	.739 (1.19)

Note. VFLU = Verbal fluency; VLE = Verbal flexibility; VOR = Verbal originality; FOR = Figural originality; FEL = Figural elaboration; FTIT = Figural title; GDET = Graphic details; EF = Executive functions; DT = Divergent thinking; PLAN = Planning; WM = Working memory; FINT = Flexibility interference; FPER = Flexibility perseverance; M = Masculine; F = Feminine
*p < .05

Table 5
Hierarchical regression analysis models to predict intelligence influence.

		FSIQ	CVI	FRI
Model 1	Gender ß (*t*)	-.114 (-1.43)	-.181 (-2.295*)	-.180 (-2.282*)
	Age ß (*t*)	.023 (.283)	.057 (.723)	.034 (.428)
	R^2	.014	.038	.035
Model 2	Gender ß (*t*)	-.116 (-1,486)	-.175 (-2.274*)	-.178 (2.257*)
	Age ß (*t*)	-.044 (-.542)	-.020 (-.249)	.003 (.041)
	Planning ß (*t*)	.131 (1.575)	.245 (3.007**)	.036 (.424)
	Working Memory ß (*t*)	.237 (2.299*)	.143 (1.413)	.195 (1.884)
	Flex. Interference ß (*t*)	.211 (1.993*)	.132 (1.266)	.223 (2.088*)
	Flex. Perseverance ß (*t*)	-.013 (-.111)	.022 (.200)	.001 (.008)
	R^2	.091*	.125**	.080
	$\triangle R2$	,077	.087	.046
Model 3	Gender ß (*t*)	-.109 (-1.391)	-.174 (-2.324*)	-.181 (-2.274*)
	Age ß (*t*)	-.069 (-.838)	-.046 (-.586)	-.012 (-.160)
	Planning ß (*t*)	.118 (1.407)	.227 (2.832**)	.041 (.481)
	Working Memory ß (*t*)	.197 (1.871)	.108 (1.073)	.194 (1.819)
	Flex. Interference ß (*t*)	.183 (1.720)	.099 (.970)	.218 (2.014*)
	Flex. Perseverance ß (*t*)	-.008 (-.065)	.056 (.511)	.033 (.282)
	Verbal Fluency ß (*t*)	-.109 (-.556)	-.158 (-.843)	-.321 (-1.613)
	Verbal Flexibility ß (*t*)	.226 (1.268)	.175 (1.030)	.259 (1.431)
	Verbal Originality ß (*t*)	-.023 (-.169)	.118 (.907)	.095 (.683)
	Figural Originality ß (*t*)	-.034 (-.412)	-.075 (-.940)	-.107 (-1.269)
	Figural Elaboration ß (*t*)	.048 (.561)	-.027 (-.326)	-.012 (-.134)
	Figural Title ß (*t*)	.148 (1.690)	.257 (3.079**)	.096 (1.085)
	Graphic Details ß (*t*)	.051 (.609)	.058 (.723)	.074 (.878)
	R^2	.145	.221*	.120
	$\triangle R2$	.054	.096	.040

Note. FISQ = Full Scale IQ; CVI = Comprehension Verbal Index; FRI = Fluid Reasoning Index; ß = Standardized beta coefficient; t = Student t coefficient; *R2* = Variance explained; $\triangle R2$ = Change in variance explained.
* *p* < .05; ** *p* < .01; ***, *p* < .001.

Finally, one future line of research would be to test the relationship between the variables described here (EF and DT), considering other EF such as inhibition and other types of creative thinking such as CT. In addition, it is crucial to further investigate the potential of VR tools in assessing and intervening in cognitive processes, such as EF. It would also be interesting to carry out a cross-cultural study to analyze the progression of these variables in other cultures where different educational systems promote them to different extents. This would help us to highlight the need for schools to work on EF in order to improve not only students' creativity but also their skills. Furthermore, it would be interesting to carry out a comparative study of these variables in normotypical samples, with educational needs, and with medical conditions (García et al., 2014; Lonergan et al., 2019; Operto et al., 2020) (Tables 4 and 5).

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CRediT authorship contribution statement

Tania Pasarín-Lavín: Writing – original draft, Methodology, Data curation, Conceptualization. **Trinidad García:** Project administration, Methodology, Funding acquisition, Formal analysis. **Celestino Rodríguez:** Supervision, Project administration, Funding acquisition. **José Carlos Núñez:** Writing – review & editing, Visualization. **Débora Areces:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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