JOURNAL OF
Creative Behavior
Publication of the Creative Education Foundation™

ROBIN H. WILLEMSEN
ISABELLE C. DE VINK
EVELYN H. KROESBERGEN
ARD W. LAZONDER

Strengthening Creative Problem-Solving within Upper-Elementary Science Education

ABSTRACT

This intervention study examined the effectiveness of instructional support tailored toward two techniques (i.e., random associations and constraint identification) to strengthen children's creative problem-solving skills within upper-elementary science education. Five inquiry-based science lessons with ample opportunity for creative problem-solving (i.e., divergent and convergent thinking) were provided. Children were assigned to a condition with instructional support (n = 107) or without (n = 134). Domain-general and specific measures of divergent and convergent thinking were included, and reading comprehension as well as mathematical ability were taken into account. Repeated measures multivariate analyses of covariance revealed how all children improved in terms of domain-general convergent thinking, with a larger increase for children who performed better in mathematics. This shows a promising premise for future research focusing on the domain generality of convergent thinking and for the potential of transfer across domains. No additional improvement based on instructional support was found and children did not improve in terms of divergent thinking. The constraint identification and random associations technique might not be suitable for elementary school children, yet future research is necessary to validate such claims. Meanwhile, teachers could possibly support convergent thinking by simply providing exercises for divergent and convergent thinking.

Keywords: creative problem-solving, divergent thinking, convergent thinking, inquiry-based education, science education.

Educational experts emphasize that our educational systems should create room for creative problem-solving (e.g., Larson & Miller, 2011; OECD, 2019), yet teachers find it hard to incorporate creativity into their classroom (Patston, Kaufman, Cropley, & Marrone, 2021; Schacter, Thum, & Zifkin, 2006). This mismatch between educational experts' beliefs and educational practice is likely because the objectives laid within curriculum constrain possibilities for creative problem-solving (Dobbins, 2009). However, when a learning environment is constructed in terms of ill-defined problems that can be solved in various ways and through multiple solutions, creative problem-solving becomes a necessity (Baer & Garrett, 2010; Beghetto & Plucker, 2006; Cropley & Cropley, 2010). The science curriculum is one environment in which ill-defined problems are introduced, when children conduct their own investigations through inquiry-based lessons (Akerson & Bartels, 2023; De Haan, 2011; Pedaste et al., 2015). The goal of the current study is to examine the effectiveness of an intervention aiming to strengthen creative problem-solving within upper-elementary science education.

Creative problem-solving can be broadly defined as seeking original ways to reach goals when the means to do so are not readily apparent and is typically divided into two core modes of thought: divergent and convergent thinking (Brophy, 2001; Childs et al., 2022; Guilford, 1973). Divergent thinking refers to the ability to view a problem from different angles, leading to various creative ideas (Guilford, 1973; Plucker & Renzulli, 1999; Runco, 2010). During creative problem-solving, multiple solution strategies must be developed to effectively solve ill-defined problems (Cropley, 2006). These solution strategies must subsequently be evaluated and implemented in order to move toward the best possible solution (convergent thinking). Convergent thinking can be defined as integrating, synthesizing, and evaluating the opportunities offered through divergence, leading to decisions regarding constraints, criteria, strategy, solution process, and ultimately to a (creative) solution (Guilford, 1973; Lubart, 2016). The process of divergent and convergent thinking is typically thought of as cyclical, with multiple iterations of divergent and convergent thinking resulting in a solution to a problem (Brophy, 2001; Childs et al., 2022; Lubart, 2018). Although many debate about what, exactly, constitutes as a creative solution, researchers agree that a creative solution is both original and effective (Runco & Jaeger, 2012).

Theories on the domain specificity of creative problem-solving underline how divergent and convergent thinking are necessary for creativity across all domains, but are applied differently depending on the domain or task at hand (Baer & Kaufman, 2005; Plucker & Beghetto, 2004; Sternberg, 2005). Although the general influence of divergent thinking across domains is relatively well researched (e.g., Kaufman, Evans, & Baer, 2010), and validated among elementary school children (Willemsen, Schoevers, & Kroesbergen, 2020), no research as-to-yet seems to focus on convergent thinking. As divergent and convergent thinking could be seen as two sides of the same coin (i.e., creative problem-solving), we hypothesize that children in our study will increase on domain-specific and domain-general measures of divergent and convergent thinking.

STRENGTHENING CREATIVE PROBLEM-SOLVING

The current study aims to strengthen creative problem-solving through instructional support focussed on the random association technique (Gu, Ritter, Delfmann, & Dijksterhuis, 2022; Malycha & Maier, 2017) and the constraint identification technique (Medeiros, Steele, Watts, & Mumford, 2018). Research investigating these techniques among elementary school children seems limited, yet adult studies underline the potential effectiveness of both techniques. With the random association technique children generate associations to a random stimulus and subsequently link these associations to the task at hand (Gu et al., 2022; Malycha & Maier, 2017). Herein, children are first asked to think of a random object (e.g., an elephant), then to think of different characteristics of this object (e.g., large ears, tail, trunk), and finally to apply these characteristics to the problem at hand (e.g., use "trunk" in a research question about a boat). Previous research among adults found this technique to increase students' capacity to think of multiple and different ideas (Gu et al., 2022) and found that the originality of ideas increased (Malycha & Maier, 2017).

The constraint identification technique asks people to determine any inherently limiting or restricting force (e.g., specific focus, limited time, stringent requirement) and then asks them to apply these constraints on ideas generated (Medeiros et al., 2018). Research among engineering students showed that merely generating creative ideas is not enough to promote the development of creative concepts (Starkey, Toh, & Miller, 2016; Zheng, Ritter, & Miller, 2018). Students often value technical feasibility during the concept selection process and select feasible ideas at the cost of originality. Thus, the evaluation and selection of ideas does not, generally, lead to creative outcomes. This is possibly due to the constraints that students identify. That is, students who identify the feasibility as a constraint but fail to identify "an original outcome" as a constraint will most likely reach uncreative outcomes. Therefore, identifying the task constraint of "an original outcome" and subsequently evaluating ideas based on this constraint (as well as more practical constraints) will be at the core of the constraint identification technique in the current study. Herewith, the constraint identification technique (as applied in this study) focuses on originality and effectiveness, in line with the standard definition of creativity proposed by Runco and Jaeger (2012).

According to the review of Scott, Leritz, and Mumford (2004), the delivery method is imperative for the effectiveness of any technique aimed to strengthen creative problem-solving. To effectively strengthen creative problem-solving, a realistic and complex context should be created (e.g., an inquiry-based science context). In terms of instructional support, children should receive an introduction and explanation of (the importance of) the technique, followed by an illustration of the technique (e.g., random associations for divergent thinking and constraint identification for convergent thinking). Next, children should be given an opportunity to practice the technique themselves and motivational feedback should be provided. Content feedback should only be given during convergent thinking exercises as content feedback could be counterproductive for divergent thinking. We hypothesize that an intervention structured in such a manner, focusing on random associations and constraint identification, would increase children's divergent and convergent thinking within an inquiry-based science context.

THE DOMAIN OF SCIENCE

In the current study, the iterative nature of creative problem-solving (Brophy, 2001; Childs et al., 2022; Lubart, 2018) is appealed to by focussing on divergent and convergent thinking across multiple phases of the scientific inquiry process, namely (1) the construction of research questions, (2) designing experiments, and (3) evidence evaluation (e.g., Pedaste et al., 2015). For the construction of research questions, some research among elementary school children found divergent thinking of importance (Lee & Cho, 2007). Although a little less researched, a study among fifth-grade children found convergent thinking to be of particular relevance too (Willemsen, de Vink, Kroesbergen, & Lazonder, 2023). No research as-to-yet seems to validate the relationship between designing experiments and creative problem-solving. Possibly, divergent thinking could be necessary when thinking of multiple, different experimental designs, whereas convergent thinking could be of importance when implementing constraints (e.g., changing one variable at a time) and when choosing experiments to conduct. During evidence evaluation, children need to search for explanations for their findings. As this process requires an open mind and a search for (multiple) alternative explanations (Chinn & Malhotra, 2002), a relationship with divergent thinking seems plausible. For convergent thinking, previous research found a relationship with evidence evaluation (Willemsen et al., 2023), as well as with more specific skills related to evidence evaluation, such as syllogistic reasoning (Lin & Shih, 2016). Although research as-to-yet seems limited, these findings suggest that divergent and convergent thinking are appealed to throughout the scientific inquiry process.

As this study focuses on creative problem-solving within the domain of science, factors specific to this domain could affect the intervention's effectiveness. Previous studies showed how scientific reasoning skills are dependent on a certain level of reading comprehension (Mayer, Sodian, Koerber, & Schwippert, 2014; Schlatter, Molenaar, & Lazonder, 2020) and mathematical ability (Koerber & Osterhaus, 2019; Schlatter et al., 2020). As a result, children who are better in reading and mathematics probably progress through science lessons more easily, leaving more cognitive capacity for practicing divergent and convergent thinking. This would affect the overall effectiveness of an intervention within this context, which is why we hypothesize that reading comprehension and mathematical ability positively affect children's learning and application of divergent and convergent thinking.

THIS STUDY

The overarching goal of this study is to examine the effectiveness of an intervention within an inquiry-based science context, which includes instructional support for the random associations and constraint identification technique so as to strengthen divergent and convergent thinking, while taking mathematical ability and reading comprehension into account. We hypothesize that this intervention would increase children's divergent and convergent thinking on domain-specific and domain-general measures. Additionally, we hypothesize that reading comprehension and mathematical ability would positively affect children's learning and application of divergent and convergent thinking skills.

METHOD

PARTICIPANTS

In the fall of 2021, 11 classes from 6 schools in the central part of the Netherlands participated in an intervention study. All classrooms received five 1-h lessons as part of their regular science curriculum, while a pre- and posttest were administered in the days prior to and after the lesson series. Along with the pre- and posttests, the worksheets children filled out during the lessons were collected for analyses. Descriptive information and progress monitoring scores on standardized test for mathematics and reading comprehension were obtained from the schools. The current study focusses on a subset of the main sample, which includes nine classes from four schools. The final sample for this paper consisted of 241 children (22 fourth graders, 89 fifth graders, and 129 sixth graders). Children were between 9 and 13 years of age ($M = 10.65$), and approximately 56% was female. Participants were divided across conditions, with the intervention condition encompassing four classes ($n = 107$) and the control condition five classes ($n = 134$). Classes were randomly divided into the conditions with or without instructional support, and the pre- and posttests were also administered in a randomized order. The research has been independently reviewed by the Ethics Committee Social Sciences (#ECSW-2021-08) of the Radboud University, and there is no formal objection. Based on our previous work (De Vink, Willemsen, Keijzer, Lazonder, & Kroesbergen, 2023), which used a similar statistical approach, we estimated that a sample of 170 children would yield a power of 95% in case of a small to medium effect size.

LESSON SERIES

Children engaged in five science lessons structured similarly around research questions, hypothesis, experiments, and conclusions (for an overview, see Figure 1). Children started each lesson with the

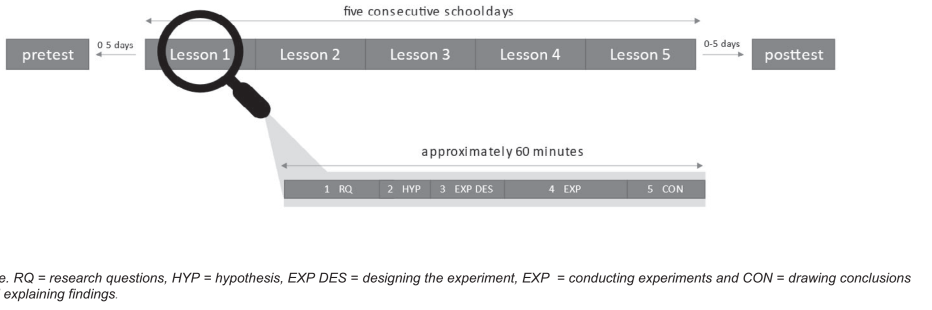

FIGURE 1. Graphic overview of the lesson series.
Note. CON = drawing conclusions and explaining findings; EXP DES = designing the experiment; EXP = conducting experiments; HYP = hypothesis; RQ = research questions.

generation and selection of creative research questions based on the central research topic of the day (Step 1; 15 min). Facilitating all possible research questions was not feasible, which is why children were subsequently introduced to the research question that they were going to examine and were shown the materials available for the experiment (see Table 1). Children were subsequently asked to write down their hypotheses based on this information (Step 2; 5 min). Next, children were given the opportunity to generate experimental designs (i.e., drawings of experiments) and were asked to select their most creative designs (Step 3; 10 min). In groups of 3–4, experimental designs were tested in a hands-on research setting (Step 4; 15 min). During the experiment, children reported their findings individually on a worksheet. Children wrote their conclusion down, generated multiple explanations for their findings, and selected their most creative explanations (Step 5; 10 min).

This lesson structure gave room for divergent and convergent thinking during step 1, 3, and 4 (see Figure 1). For each of these steps, children were given 5 min to generate ideas individually (i.e., the worksheet measure of divergent thinking). Notably, the research questions and materials provided to children were purposefully chosen to create an open-ended research environment, providing ample opportunity for creative thinking. The topics of these lessons are presented in Table 1.

INSTRUCTIONAL SUPPORT

Although the structure for each lesson was the same across classes, different instructions were given for two different conditions. The Dutch instructional support for both conditions can be found in OSF.

Intervention condition

In the intervention condition, children were taught *how* to be creative. In line with the findings of Scott et al. (2004), the processes of divergent and convergent thinking were introduced, explained, and exemplified before children were given the opportunity to practice these skills. In general, children were taught that creative thinking encompasses the generation of ideas (divergent thinking) as well as the selection of ideas (convergent thinking). In addition, children were taught that you can generate many ideas (fluency), ideas that are different from each other (flexibility), and ideas that your neighbor would not think of (original). The generation of many, flexible and original ideas was exemplified. Subsequently, we showed how random associations can lead to ideas that are flexible and original. For example, when thinking of experimental designs for boats (lesson 1), the characteristics of an elephant were discussed to show how these can help with the generation of flexible and original ideas (e.g., one idea could be to design a boat in which the stability of the boat is increased by “elephant-tail-like” protrusions). After the introduction, explanation, and exemplification of these techniques, children were given the opportunity to practice divergent thinking (see worksheet).

In terms of convergent thinking, we discussed how creative ideas are original and effective (conform Runco & Jaeger, 2012). The constraint identification technique was subsequently explained and exemplified

TABLE 1. Overview of Topic, Research Question, and Material Provided per Lesson

	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Topic	Boat	Swing	Tower	Plane	Bridge
Research Question	What affects the floating capacity of a boat?	What affects the period of a pendulum?	What affects the stability of a tower?	What affects the flight distance of a plane?	What affects the carrying capacity of a bridge?
Materials	Sheets of aluminum foil for boats, basin of water, marbles	Stick, three lengths of rope, stopwatch, playdough as weight	Spaghetti, marshmallows (10 per group)	Paper (A4) for planes, scissors, adhesive tape, ball of yarn, flight path (consisting of 1-meter markers to estimate distance)	Two wooden blocks per group (outside pillars), paper (A4) for bridge, adhesive tape, books as weights

to show how you can take these constraints into account when choosing your most creative idea. For example, when selecting creative research questions about boats (lesson 1), the most creative idea should be about boats, should be a question that you can actually research, and should be (the most) original. Afterward, children had the opportunity to practice convergent thinking (see worksheet).

For the instructional support, the principle of fading was administered. As such, the first lesson consisted of the most elaborate explanations and examples and took approximately 15 min longer than the control condition. This ensured that children in all conditions practiced an equal amount of time. This resulted in approximately 15 min of practice per lesson, divided over three steps (see Figure 1). The explanations and examples given during the following lessons were adapted based on the understanding of children.

Control condition

In the control condition, children were told that creative ideas are original and effective (conform Runco & Jaeger, 2012) and were given the opportunity to practice the generation and selection of creative ideas (see worksheet). Children in the control condition did not receive any further instructional support. That is, we did not explicitly discuss the generation and selection of ideas, nor the differences between fluency, flexibility, and originality. Lastly, we did not discuss the random associations and constraint identification techniques.

INSTRUMENTS

Pre- and posttest

For divergent thinking, two versions of the fifth activity of the verbal Torrance Test of Creative Thinking (TTCT; Torrance, 2008) were administered as a pre- and posttest. Children had 10 min to write down as many possible, original, alternative uses for a cardboard box (version A) or a soda can (version B) as they could. Scores were obtained for fluency (i.e., number of answers), flexibility (i.e., number of categories of answers), and originality (i.e., originality of given answers). Fluency and flexibility were based on the guidelines of the test manual. As the originality ratings were outdated and unsuitable for children, originality scores were created separately. Originality was determined by first counting all the ideas provided by the entire sample available. Next, quintile scores based on the prevalence of these ideas were created, with higher scores representing more original ideas (0.2; 0.4; 0.6; 0.8; 1.0; adapted from Kattou, Kontoyianni, Pitta-Pantazi, & Christou, 2013). If an idea was inappropriate for the task at hand or if a child mentioned an idea for a second time, the idea received a score of 0. The final originality score of a child was the sum of the quintile scores belonging to the ideas the child had generated. Thus, the higher the score, the more original the child. Prior studies examining psychometric properties of the TTCT report sufficient-to-good validity and reliability (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005; Krumm, Aranguren, Arán Filippetti, & Lemos, 2016).

For convergent thinking, the Remote Associates Test for children (RATje; Lazonder et al., 2022) was administered as a pre- and posttest. Psychometric properties have been validated in terms of validity and reliability for the RATje in general (Lazonder et al., 2022). Test items presented three stimuli words (e.g., worm, case, marker) for which children had to find a solution word (book) that was either a prefix or suffix to all three stimuli words (bookworm, bookcase, bookmarker). Children received plenary instructions and were given 3 min and 20 s to write down their answers. Their final score was the sum of correct answers (range 0–5). For our study, the 10 original items were distributed across two versions of five items each. Distribution of items was based on their difficulty rating, with each version having a similar build-up in difficulty. Split-half reliability based on the data of Lazonder et al. (2022) proved sufficient (r = .57), with the difficulty of both versions proving similar too: proportion correct of .47 for version A and .44 for version B. Data from the current study proved similar in difficulty, with a proportion correct of .48 for version A and .56 for version B.

Worksheets

To assess creative thinking within the domain of science, the worksheets from the first and final lesson were assessed. Divergent and convergent thinking scores were obtained for (1) constructing research questions, (2) experimental designs, and (3) evaluating evidence. The original (i.e., Dutch) worksheets and an exemplary translation are available in OSF, and an example of one divergent and convergent cycle can be found in Figure 2.

For divergent thinking, children were given 5 min to generate as many original ideas as they could for the respective task. Similar to the TTCT, divergent thinking scores were based on fluency (i.e., the number of ideas), flexibility (i.e., the number of categories to which these ideas belonged), and originality (i.e., the originality of these ideas). Originality scores for each answer were calculated in a similar manner as the TTCT originality scores. Additionally, categories for flexibility were created through close examination of the ideas provided by the same children and were only included upon agreement between two raters.

To give an indication of children's convergent thinking during the lesson series, children made a top-3 of their most original ideas applicable to this particular task (see assignment 2 in Figure 1). The extent to which the child's ranking matched the actual ranking was compared based on originality scores. As ideas that were inappropriate for the task at hand were given a score of 0 during the scoring of originality, this was deemed a decent descriptor of originality and appropriateness. For every idea in their top-3, children could receive one point (range 0–3). If a child selected the most original idea as first place, the second most original idea as second and the third most original idea as third, full points were awarded. These points were divided by the number of answers given, resulting in a final CT score within the range of 0–1. If the child had only one idea to choose from, convergent thinking was not taken into account.

Reading and mathematics

In the Netherlands, children's academic achievement is usually administered through the National Institute for Educational Testing and Assessment (in Dutch: Stichting Cito Instituut voor Toetsontwikkeling). The latest standardized scores of the mathematical achievement test and reading comprehension test were obtained (Engelen & Hop, 2017; Hiddink, Jolink, Tomesen, & Weekers, 2017). As one school used an alternative test (IEP; Langeveld et al., 2015), equipercentile equating was performed to convert the IEP scores to the Cito scale (Finch, French, & Immekus, 2016; Shea & Norcini, 1995). The mathematical achievement tests consisted of questions relating to domains such as arithmetical operations, number line estimations, fractions, and percentages, while the reading comprehension tests consisted of questions in which formal and informal texts were discussed (e.g., most appropriate summary, best prediction of missing section). Psychometric properties of these tests indicate good validity and reliability (Engelen & Hop, 2017; Hiddink et al., 2017; Langeveld et al., 2015).

DATA ANALYSES

The analytic plan was to first investigate missing values in SPSS Statistics 27 (IBM Corp, 2021), after which the relationships between fluency, flexibility, and originality of divergent thinking measures were examined. Descriptive analyses were subsequently run to assess outliers, normality, homogeneity of (co)variances, correlations, and differences between classes/grades. Repeated measures multivariate analysis of

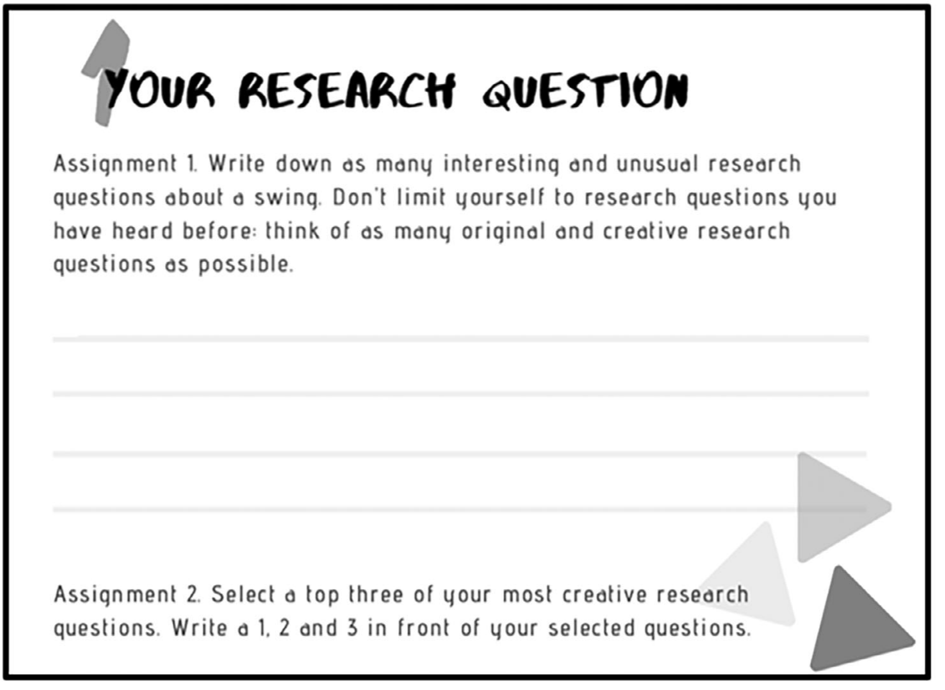

FIGURE 2. Example of the divergent and convergent thinking cycle within the generation of research questions.

covariance (RM-MANCOVA) was conducted with time as within-subject factor, instructional condition as between-subject factor, divergent and convergent thinking as dependent variables, and mathematics and reading comprehension as covariates. Two RM-MANCOVAs were conducted, with one analysis focussing on the pre- and post-test and one focussing on the worksheets. Partial eta square (η_p^2) was reported as a measure of effect size.

RESULTS

PRELIMINARY ANALYSES

Data were first analyzed to determine an appropriate manner of handling missingness. One participant missed data on more than half of the variables and was excluded from subsequent analyses. Of the remaining participants, 67% had at least some missing data, which amounted to a total of 8% missing data. Little's MCAR test showed that missingness was not completely at random, $\chi^2(2195) = 2341.13$, $p = .015$. The number of children unable to generate more than one idea on divergent thinking tasks made a score for convergent thinking often impossible, resulting in a pattern of missingness centered around the convergent thinking measures. To correct this pattern, the fully conditional specification (FCS) method of multiple imputation was administered. As differences between iterations were negligible, the findings of one random iteration out of five will be reported. Multiple imputation was deemed appropriate as this allowed us to retain all collected data in our main analyses. Additionally, FCS is a robust method which handles missingness adequately when not completely at random (Van Buuren, Brand, Groothuis-Oudshoorn, & Rubin, 2006).

Descriptive statistics for the measures used in the main analyses are shown in Table 2. For every measure, fluency, flexibility, and originality were highly correlated ($r = .71–.99$) and were therefore aggregated into one divergent thinking score by adding z-scores (for an overview of all correlations, see OSF). Because these scores were highly correlated to the original scores of fluency, flexibility, and originality (r = .92–.99), the aggregated divergent thinking scores were used in the main analyses.

To ensure the accuracy of our analyses, outliers, normality, multicollinearity, and homogeneity of (co) variances were assessed. We furthermore evaluated whether there were any consistent a priori differences between classes and grade levels. A visual inspection of boxplots revealed no outliers except for two realistic scores for high achieving creative children. Scores for skewness and kurtosis showed normal distributions for each of the conditions (i.e., values between −3.29 and 3.29). Box's M tests indicated homogeneity of covariances and Levene's test indicated homogeneity of variances for all but two variables. As our sample sizes were large, this small deviation from homogeneity was of no concern (Allen, Bennett, & Heritage, 2018). Correlations between variables showed no signs of multicollinearity (see the correlation matrix in OSF). Additionally, reading comprehension and mathematics showed moderate correlations with several dependent variables, illustrating the relevance of these covariates.

In a final preparatory step, the occurrences and magnitude of class and grade differences were evaluated. Herewith, we aimed to determine whether we should correct for class and grade differences in our main analyses. Differences in growth were evaluated for the eight measures of divergent and convergent thinking for grade and class separately, resulting in 16 comparisons (see OSF). A visual inspection of these growth patterns revealed differences across classes and grades, with some scores increasing in some classes/grades and decreasing in other classes/grades. For example, grade 6 showed a slight increase in divergent thinking on the TTCT, whereas grade 4 and 5 showed a decrease (see Table 3). These differences were never systemic, because the grade/class showing an opposite trend differed across variables. As the visual inspection of differences per class and grade levels showed no systemic differences, the main analyses could proceed as planned.

TABLE 2. Descriptives of Children's Test Scores

	Control			**Intervention**		
	EMM	***M***	***SD***	**EMM**	***M***	***SD***
Test scores						
DT pretest	−.07	−.07	2.91	.09	.09	2.88
DT posttest	−.10	−.08	3.00	.12	.10	2.75
CT pretest	2.62	2.63	1.39	2.15	2.14	1.28
CT posttest	2.93	2.97	1.48	2.62	2.57	1.34
Worksheets divergent thinking						
RQ lesson 1	−.06	−.04	2.86	.08	.04	2.90
RQ lesson 5	.19	.21	3.17	−.23	−.26	2.42
EXP LESSON 1	.01	.05	3.00	−.01	−.06	2.59
EXP lesson 5	−.33	−.32	2.78	.41	.39	2.78
EE lesson 1	.15	.15	3.10	−.19	−.19	2.59
EE lesson 5	.18	.19	2.71	−.22	−.24	2.98
Worksheets convergent thinking						
RQ lesson 1	.68	.68	.31	.74	.74	.30
RQ lesson 5	.64	.65	.34	.69	.68	.36
EXP lesson 1	.55	.56	.40	.68	.67	.36
EXP lesson 5	.60	.60	.37	.56	.56	.38
EE lesson 1	.41	.41	.35	.44	.44	.32
EE lesson 5	.42	.42	.38	.42	.42	.36

Note. $n_{control}$ = 134, $n_{intervention}$ = 107. The estimated marginal means (EMM) are corrected for reading comprehension (M = 194.89) and mathematics (M = 249.06). Divergent thinking scores are z-scores and therefore include negative values. CT = convergent thinking; DT = divergent thinking; EE = evidence evaluation; EXP = experimental design; RQ = research question.

MAIN ANALYSES

Pretest and posttest scores

The RM-MANCOVA on the pre- and posttest showed an effect of time, $F(2, 236) = 6.25$, $p = .002$, $\eta_p^2 = .05$, and an effect of condition, $F(2, 236) = 4.62$, $p = .011$, $\eta_p^2 = .04$. No interaction effect between time and condition was found, $F(2, 236) = 0.37$, $p = .694$, $\eta_p^2 = .003$. This means that children improved on one or more tasks over time and that differences across conditions were prevalent, but that conditions did not differ in the change of divergent and/or convergent thinking over time. Additionally, reading comprehension, $F(2, 236) = 7.232$, $p < .001$, $\eta_p^2 = .06$, and mathematics, $F(2, 236) = 3.987$, $p = .020$, $\eta_p^2 = .03$, had a significant effect on the model in general, and an interaction effect between time and mathematics was found, $F(2, 236) = 3.891$, $p = .022$, $\eta_p^2 = .03$. Thus, children scoring high on mathematics performed better on divergent and/or convergent thinking over time.

Follow-up univariate analyses of the main variables showed significant effects for convergent but not divergent thinking. Specifically, an increase over time was found for convergent thinking, $F(1, 202) = 9.34$, $p = .003$, $\eta_p^2 = .04$, but not for divergent thinking, $F(1, 202) = 2.25$, $p = .135$, $\eta_p^2 = .01$. The effect of condition was significant for convergent thinking, $F(1, 202) = 7.68$, $p = .006$, $\eta_p^2 = .03$, yet divergent thinking did not differ across conditions, $F(1, 202) = 0.34$, $p = .558$, $\eta_p^2 = .001$. Profile plots similarly showed that the control condition scored systematically higher on convergent thinking.

Follow-up univariate analyses of the covariates showed that mathematical ability affected both divergent thinking, $F(1, 237) = 5.114$, $p = .025$, $\eta_p^2 = .02$, and convergent thinking, $F(1, 237) = 4.923$, $p = .027$, $\eta_p^2 = .02$, whereas reading comprehension was only important for divergent but not convergent thinking, $F(1, 237) = 7.487$, $p = .007$, $\eta_p^2 = .03$, and $F(1, 237) = 3.548$, $p = .061$, $\eta_p^2 = .02$. A positive interaction between time and mathematics was found for convergent thinking, $F(1, 202) = 7.587$, $p = .006$, $\eta_p^2 = .03$, but not for divergent thinking, $F(1, 202) = 0.048$, $p = .927$, $\eta_p^2 = .00$.

Worksheet scores

The RM-MANCOVA on the worksheet showed no effect of time, $F(6, 232) = 1.09$, $p = .367$, $\eta_p^2 = .03$ and no effect of condition, $F(6, 232) = 1.567$, $p = .158$, $\eta_p^2 = .04$, but the interaction effect between time and condition showed merits for further scrutiny of univariate results, $F(6, 232) = 1.887$, $p = .084$, $\eta_p^2 = .05$. Mathematical ability had an effect on (at least some of) the divergent and convergent thinking measures, $F(6, 232) = 4.074$, $p < .001$, $\eta_p^2 = .10$, whereas reading comprehension showed no associations, $F(6, 232) = 1.041$, $p = .399$, $\eta_p^2 = .03$.

Follow-up univariate analyses revealed insignificant time × condition interactions for all worksheet measures except convergent thinking in terms of experimental designs, $F(1, 237) = 6.405$, $p = .012$, $\eta_p^2 = .03$. Profile plots indicated that the intervention condition decreased in performance over time, while the control condition remained almost equal. Finally, mathematical ability had a positive effect on divergent and convergent thinking of research questions, $F(1, 237) = 6.359$, $p = .012$, $\eta_p^2 = .03$, and $F(1, 237) = 15.363$, $p < .001$, $\eta_p^2 = .06$ respectively.

DISCUSSION

The overarching goal of this study was to examine the effectiveness of an intervention aiming to strengthen divergent and convergent thinking within an inquiry-based science unit, while taking mathematical ability and reading comprehension into account. We hypothesized that this intervention would increase children's divergent and convergent thinking on domain-specific and domain-general measures. Additionally, we hypothesized that reading comprehension and mathematical ability would positively affect children's learning and application of divergent and convergent thinking skills.

TABLE 3. Example of Growth Differences Across Grades, for General Divergent Thinking

Grade	Average score divergent thinking, pretest	Average score divergent thinking, posttest
4	0.33	−0.81
5	−0.35	−0.15
6	0.19	0.28

Although previous research indicates that divergent thinking training (Scott et al., 2004) and the random associations technique specifically (Gu et al., 2022; Malycha & Maier, 2017) are effective strategies in strengthening divergent thinking, children in our study showed no differences over time or across conditions in terms of domain-general divergent thinking. Domain-specific divergent thinking showed no differences across conditions either (differences over time could not be assessed because lesson content differed). Several factors might explain these nonsignificant effects, such as the serial order effect and children's motivation. The serial order effect describes how people reach more original and flexible answers on divergent thinking tasks as time progresses (Bai, Leseman, Moerbeek, Kroesbergen, & Mulder, 2021; Wang, Hao, Ku, Grabner, & Fink, 2017). In this study, each divergent thinking exercise lasted approximately five minutes, as to diminish the repetitiveness children could feel when ideating for longer periods of time. However, a larger time frame might yield better results (at least in terms of originality). There is a longstanding belief that task-focused and intrinsic motivation is important for the expression of creativity (e.g., Sternberg & Lubart, 1992). Recent research furthermore indicates that intrinsic motivation is important for creative achievement in science (Du et al., 2019). Children's motivation might have been hampered in the current study because children were given the same divergent thinking exercises (albeit focused on different topics) three times a day, five days in a row. An intervention in which sessions are more spread out over time could prove promising for fostering divergent thinking, as this might keep children more motivated.

Similarly to divergent thinking, no difference between performance of children in the condition with or without instructional support was found for convergent thinking. The instructional support administered the constraint identification technique, in which people are asked to determine any inherently limiting or restricting force (e.g., specific focus, limited time, stringent requirement) and are then asked to apply these constraints on decisions made. The constraint identification technique did not lead to an improvement in domain-general nor domain-specific measures and even decreased convergent thinking during the experiment design phase. While the constraint identification technique proved effective in previous studies with adult samples (Medeiros et al., 2018; Scott et al., 2004), a parallel study found the technique to be ineffective for promoting children's mathematical convergent thinking skills (de Vink et al., 2023). It seems plausible that this technique is too complex for children aged 9–13, yet more evidence is necessary to validate such claims. Alternatively, the extensive practice opportunities in this study could have already increased children's convergent thinking to such an extent that the added benefit of the constraint identification technique became negligible. Future research investigating the effectiveness of the constraint identification technique and alternative convergent thinking techniques among elementary school children would be most welcome.

While there were no differences between conditions, all children improved on domain-general measures of convergent thinking. This result could be seen as support for a certain level of domain-generality within creative problem-solving (Baer & Kaufman, 2005; Sternberg, 2005), as it indicates that practice in one domain translates to a more general improvement on convergent thinking. Previous research that focused on elementary education indicates that there is considerable overlap between creativity across domains (e.g., Willemsen et al., 2020), but no research as-to-yet seems to focus on convergent thinking across domains. This study is one of the first to show that training convergent thinking in one domain (i.e., science) could potentially lead to general improvement of convergent thinking. These findings show a promising premise for future research focusing on the domain generality of convergent thinking and the potential for transfer across domains.

For this intervention study, mathematical ability and reading comprehension were taken into account. Previous studies show how scientific reasoning skills are dependent on a certain level of reading comprehension (Mayer et al., 2014; Schlatter et al., 2020) and mathematical ability (Koerber & Osterhaus, 2019; Schlatter et al., 2020). We thus expected that children who are better in mathematics and/or reading comprehension progress through a scientific inquiry cycle more easily, which would affect the overall effectiveness of an intervention within this context (i.e., an aptitude-treatment interaction). Contrary to our expectations, mathematical ability and reading comprehension did not affect the learning of divergent thinking. For convergent thinking, children who were better in mathematics improved more on domain-general convergent thinking over time. Convergent thinking and mathematical ability rely more strongly on cognitive capacities (e.g., working memory and intelligence) than divergent thinking and reading comprehension (Giofrè, Donolato, & Mammarella, 2018; Lee & Therriault, 2013; Peng, Wang, Wang, & Lin, 2019), which might be why this aptitude treatment effect was not found for divergent thinking or reading comprehension.

Several limitations should be taken into account when interpreting the present results. In our study, children improved on general convergent thinking, regardless of condition. If a condition in which children received only their regular science program would have been included in the design, we could have determined if our condition without instruction already strengthened children's creative problem-solving. Another limitation lies within the domain-specific measures of divergent and convergent thinking. As one lesson could have provided more room for creative ideas than another, we could only take the difference in change between conditions into account. Finally, lessons were scheduled five days in a row so as to minimize the risk of data loss due to a school lockdown (due to the COVID-19 pandemic). As already discussed, more practice time for divergent thinking and a larger incubation time between lessons might lead to better results. Thus, future research could focus on a lesson series in which lessons are given once a week, possibly providing more room for divergent thinking while including validated domain-specific measures of creative problem-solving.

On a more general note, future research could also focus on more advanced research tools and methods. For example, future studies building on our findings could benefit from larger sample sizes and multi-level analyses, so as to evaluate classroom and school differences more specifically. Future research could also focus on, and as a result benefit from, text-mining tools for the automized scoring of divergent thinking tasks. The usefulness of word association networks for the scoring of originality has been established in the past (Acar & Runco, 2014), and recent research shows how text-mining methods can facilitate completely autonomous scoring of originality (Acar et al., 2023). Manual scoring of the TTCT can be strenuous (Glover & Albers, 2007) and manually scoring tasks such as the worksheets in this study even more so. Unfortunately, text-mining tools have yet to be validated among (Dutch) children, which prohibited us from using text-mining tools in the current study. Thus, future research focusing on the validity of text-mining tools among children, across languages and across multiple tasks, seems beneficial for the field of creativity research.

In conclusion, this study examined the effectiveness of an intervention within an inquiry-based science context, which included instructional support for the random associations and constraint identification technique so as to strengthen divergent and convergent thinking, while taking mathematical ability and reading comprehension into account. We found that all children improved in terms of domain-general convergent thinking over time, but found no additional improvement based on instructional support. For divergent thinking, neither the lesson series nor instructional support seemed to improve children's skills. Although educational implications for divergent thinking remain unclear, teaching divergent thinking is probably best done with little time constraints (both during and between tasks). For convergent thinking, our findings suggest that a certain amount of transfer across domains is possible. This means that teachers could focus on convergent thinking in one domain and transfer the lessons taught to another domain. Although the constraint identification technique might be too difficult for elementary school children, it seems like teachers could support convergent thinking through exercises of divergent and convergent thinking cycles.

CONFLICT OF INTEREST

The authors report there are no competing interests to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

Acar, S., Berthiaume, K., Grajzel, K., Dumas, D., Flemister, C.T., & Organisciak, P. (2023). Applying automated originality scoring to the verbal form of Torrance tests of creative thinking. *Gifted Child Quarterly*, *67*(1), 3–17; doi: 10.1177/0016986221106187.

Acar, S., & Runco, M.A. (2014). Assessing associative distance among ideas elicited by tests of divergent thinking. *Creativity Research Journal*, *26*(2), 229–238; doi: 10.1080/10400419.2014.901095.

Akerson, V.L., & Bartels, S.L. (2023). Elementary science teaching: Toward the goal of scientific literacy. In N.G. Lederman, D.L. Zeidler, & J.S. Lederman (Eds.), *Handbook of research on science education (Volume III)* (pp. 528–559). New York: Routledge.

Allen, P., Bennett, K., & Heritage, B. (2018). *SPSS statistics: A practical guide with student resource* (4th edn). South Melbourne, Victoria: Cengage.

Baer, J., & Garrett, T. (2010). Teaching for creativity in an era of content standards and accountability. In R. Beghetto & J. Kaufman (Eds.), *Nurturing creativity in the classroom* (pp. 6–23). Cambridge: Cambridge University Press; doi: 10.1017/CBO9780511781629.003.

Baer, J., & Kaufman, J.C. (2005). Bridging generality and specificity: The amusement park theoretical (APT) model of creativity. *Roeper Review*, *27*(3), 158–163; doi: 10.1080/02783190509554310.

Bai, H., Leseman, P.P., Moerbeek, M., Kroesbergen, E.H., & Mulder, H. (2021). Serial order effect in divergent thinking in five-to six-year-olds: Individual differences as related to executive functions. *Journal of Intelligence*, *9*(2), 20; doi: 10.3390/jintelligence9020020.

Beghetto, R.A., & Plucker, J.A. (2006). The relationship among schooling, learning, and creativity: "All roads lead to creativity" or "you can't get there from here"? In J.C. Kaufman & J. Baer (Eds.), *Creativity and reason in cognitive development* (pp. 316–332). Cambridge: Cambridge University Press; doi: 10.1017/CBO9780511606915.019.

Brophy, D.R. (2001). Comparing the attributes, activities, and performance of divergent, convergent, and combination thinkers. *Creativity Research Journal*, *13*, 439–455; doi: 10.1207/S15326934CRJ1334_20.

Childs, P., Han, J., Chen, L., Jiang, P., Wang, P., Park, D., … Vilanova, I. (2022). The creativity diamond—A framework to aid creativity. *Journal of Intelligence*, *10*(4), 73; doi: 10.3390/jintelligence10040073.

Chinn, C.A., & Malhotra, B.A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*, 175–218; doi: 10.1002/sce.10001.

IBM Corp. (2021). *IBM SPSS Statistics for Windows, Version 27*. Armonk, NY: IBM Corp.

Cramond, B., Matthews-Morgan, J., Bandalos, D., & Zuo, L. (2005). A report on the 40-year follow-up of the Torrance Tests of Creative Thinking: Alive and well in the new millennium. *Gifted Child Quarterly*, *49*, 283–291; doi: 10.1177/001698620504900402.

Cropley, A. (2006). In praise of convergent thinking. *Creativity Research Journal*, *18*(3), 391–404; doi: 10.1207/s15326934crj1803_13.

Cropley, D., & Cropley, A. (2010). Recognizing and fostering creativity in technological design education. *International Journal of Technology and Design Education*, *20*, 345–358; doi: 10.1007/s10798-009-9089-5.

De Haan, R.L. (2011). Science education: Teaching creative science thinking. *Science*, *334*, 1499–1500; doi: 10.1126/science.1207918.

De Vink, I.C., Willemsen, R.H., Keijzer, R., Lazonder, A.W., & Kroesbergen, E.H. (2023). Supporting creative problem solving in primary geometry education. *Thinking Skills and Creativity*, *48*, 101307; doi: 10.1016/j.tsc.2023.101307.

Dobbins, K. (2009). Teacher creativity within the current education system: A case study of the perceptions of elementary teachers. *Education*, *37*(2), 95–104; doi: 10.1080/03004270802012632.

Du, Y., Xie, L., Zhong, J.A., Zou, H., Law, R., & Yan, X. (2019). Creativity fostering teacher behavior on student creative achievement: Mediation of intrinsic motivation and moderation of openness to experience. *School Psychology International*, *40*(5), 525–542; doi: 10.1177/0143034319868271.

Engelen, R., & Hop, M. (2017). *Wetenschappelijke verantwoording LVS-toetsen Rekenen-Wiskunde 3.0 voor groep 6* [Scientific justification of the mathematics 3.0 test in fourth-grade]. Cito. https://www.cito.nl/-/media/files/kennisbank/cito-bv/15-cito-lvs-rekwisk-3-0-gr6-wet-verantwoording.pdf?la=nl-nl.

Finch, H., French, B.F., & Immekus, J.C. (2016). *Applied psychometrics using SPSS and AMOS*. Charlotte, NC: Information Age Publishing.

Giofrè, D., Donolato, E., & Mammarella, I.C. (2018). The differential role of verbal and visuospatial working memory in mathematics and reading. *Trends in Neuroscience and Education*, *12*, 1–6; doi: 10.1016/j.tine.2018.07.001.

Glover, T.A., & Albers, C.A. (2007). Considerations for evaluating universal screening assessments. *Journal of School Psychology*, *45*(2), 117–135; doi: 10.1016/j.jsp.2006.05.005.

Gu, X., Ritter, S.M., Delfmann, L.R., & Dijksterhuis, A. (2022). Stimulating creativity: Examining the effectiveness of four cognitive-based creativity training techniques. *The Journal of Creative Behavior*, *56*(3), 312–327; doi: 10.1002/jocb.531.

Guilford, J. (1973). *The nature of human intelligence*. New York: McGraw-Hill Book Company.

Hiddink, L., Jolink, A., Tomesen, M., & Weekers, A. (2017). *Wetenschappelijke verantwoording LVS-toetsen Begrijpend Lezen 3.0 voor groep 6* [Scientific justification of the reading comprehension 3.0 test in fourth-grade]. Cito. https://www.cito.nl/-/media/files/kennisbank/cito-bv/18-cito-lvs-begrijpend-lezen-3-0-gr6-wet-verantwoording.pdf?la=nl-nl.

Kattou, M., Kontoyianni, K., Pitta-Pantazi, D., & Christou, C. (2013). Connecting mathematical creativity to mathematics ability. *ZDM – The International Journal on Mathematics Education*, *45*(2), 167–181; doi: 10.1007/s11858-012-0467-1.

Kaufman, J.C., Evans, M.L., & Baer, J. (2010). The American idol effect: are students good judges of their creativity across domains? *Empirical Studies of the Arts*, *28*, 3–17; doi: 10.2190/EM.28.1.b.

Koerber, S., & Osterhaus, C. (2019). Individual differences in early scientific thinking: Assessment, cognitive influences, and their relevance for science learning. *Journal of Cognition and Development*, *20*(4), 510–533; doi: 10.1080/15248372.2019.1620232.

Krumm, G., Aranguren, M., Arán Filippetti, V., & Lemos, V. (2016). Factor structure of the torrance tests of creative thinking verbal form B in a Spanish-speaking population. *The Journal of Creative Behavior*, *50*, 150–164; doi: 10.1002/jocb.76.

Langeveld, E.A., Bezdan, E., Binsbergen, M., van Silfhout, G., Haitjema, T., Bijl, E., … Fredriks, G. (2015). *IEP Eindtoets Wetenschappelijke verantwoording 2014–2015* [Scientific justification of the IEP test 2014–2015]. Bureau ICE. https://docplayer.nl/12719268-Wetenschappelijke-verantwoording-bureau-ice.html.

Larson, L.C., & Miller, T.N. (2011). 21st century skills: Prepare students for the future. *Kappa Delta Pi Record*, *47*(3), 121–123; doi: 10.1080/00228958.2011.10516575.

Lazonder, A.W., Willemsen, R.H., de Vink, I.C., Roseboom-Folmer, J., Arends, O., Jongen, A.P., … Kroesbergen, E.H. (2022). Development and validation of RATje: A Remote Associates Test for Dutch children. *Thinking Skills and Creativity*, *44*, 101042; doi: 10.1016/j.tsc.2022.101042.

Lee, H., & Cho, Y. (2007). Factors affecting problem finding depending on degree of structure of problem situation. *The Journal of Educational Research*, *101*, 113–123; doi: 10.3200/JOER.101.2.113-125.

Lee, C.S., & Therriault, D.J. (2013). The cognitive underpinnings of creative thought: A latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes. *Intelligence*, *41*(5), 306–320; doi: 10.1016/j.intell.2013.04.008.

Lin, W.-L., & Shih, Y.-L. (2016). The developmental trends of different creative potentials in relation to children's reasoning abilities: From a cognitive theoretical perspective. *Thinking Skills and Creativity*, *22*, 36–47; doi: 10.1016/j.tsc.2016.08.004.

Lubart, T. (2016). Creativity and convergent thinking: Reflections, connections and practical considerations. *Вестник Российского Университета Дружбы Народов. Серия: Психология и Педагогика*, *4*, 7–15; doi: 10.22363/2313-1683-2016-4-.

Lubart, T. (Ed.). (2018). *The creative process: Perspectives from multiple domains*. London: Springer.

Malycha, C.P., & Maier, G.W. (2017). The random-map technique: Enhancing mind-mapping with a conceptual combination technique to foster creative potential. *Creativity Research Journal*, *29*, 114–124; doi: 10.1080/10400419.2017.1302763.

Mayer, D., Sodian, B., Koerber, S., & Schwippert, K. (2014). Scientific reasoning in elementary school children: Assessment and relations with cognitive abilities. *Learning and Instruction*, *29*, 43–55; doi: 10.1016/j.learninstruc.2013.07.005.

Medeiros, K.E., Steele, L.M., Watts, L.L., & Mumford, M.D. (2018). Timing is everything: Examining the role of constraints throughout the creative process. *Psychology of Aesthetics, Creativity, and the Arts*, *12*(4), 471–488; doi: 10.1037/aca0000148\.

OECD. (2019). *Trends Shaping Education 2019*. Paris: OECD Publishing.

Patston, T.J., Kaufman, J.C., Cropley, A.J., & Marrone, R. (2021). What is creativity in education? A qualitative study of international curricula. *Journal of Advanced Academics*, *32*(2), 207–230; doi: 10.1177/1932202X20978356.

Pedaste, M., Mäeots, M., Siiman, L.A., De Jong, T., Van Riesen, S.A., Kamp, E.T., … Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61; doi: 10.1016/j.edurev.2015.02.003.

Peng, P., Wang, T., Wang, C., & Lin, X. (2019). A meta-analysis on the relation between fluid intelligence and reading/mathematics: Effects of tasks, age, and social economics status. *Psychological Bulletin*, *145*(2), 189–236; doi: 10.1037/bul0000182.

Plucker, J.A., & Beghetto, R.A. (2004). Why creativity is domain general, why it looks domain specific, and why the distinction does not matter. In R.J. Sternberg, E.L. Grigorenko, & J.L. Singer (Eds.), *Creativity: From potential to realization* (pp. 153–167). Washington, DC: American Psychological Association; doi: 10.1037/10692-009.

Plucker, J.A., & Renzulli, J.S. (1999). Psychometric approaches to the study of human creativity. In R.J. Sternberg (Ed.), *Handbook of creativity* (pp. 35–61). Cambridge: Cambridge University Press.

Runco, M. (2010). Divergent thinking, creativity, and ideation. In J.C. Kaufman & R.J. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 413–446). Cambridge: Cambridge University Press.

Runco, M.A., & Jaeger, G.J. (2012). The standard definition of creativity. *Creativity Research Journal*, *24*(1), 92–96; doi: 10.1080/10400419.2012.650092.

Schacter, J., Thum, Y.M., & Zifkin, D. (2006). How much does creative teaching enhance elementary school students' achievement? *Journal of Creative Behavior*, *40*, 47–72; doi: 10.1002/j.2162-6057.2006.tb01266.x.

Schlatter, E., Molenaar, I., & Lazonder, A.W. (2020). Individual differences in children's development of scientific reasoning through inquiry-based instruction: Who needs additional guidance? *Frontiers in Psychology: Developmental Psychology*, *11*, 904; doi: 10.3389/fpsyg.2020.00904.

Scott, G., Leritz, L.E., & Mumford, M.D. (2004). The effectiveness of creativity training: A quantitative review. *Creativity Research Journal*, *16*(4), 361–388; doi: 10.1080/10400410409534549.

Shea, J.A., & Norcini, J.J. (1995). Equating. In J.C. Impara (Ed.), *Licensure testing: Purposes, procedures, and practices* (pp. 253–287). Lincoln, NE: Buros Institute of Mental Measurements.

Starkey, E., Toh, C.A., & Miller, S.R. (2016). Abandoning creativity: The evolution of creative ideas in engineering design course projects. *Design Studies*, *47*, 47–72; doi: 10.1016/j.destud.2016.08.003.

Sternberg, R.J. (2005). The domain generality versus specificity debate: How should it be posed? In J.C. Kaufman & J. Baer (Eds.), *Creativity across domains: Faces of the muse* (pp. 299–306). London: Lawrence Erlbaum Associates, Publishers.

Sternberg, R.J., & Lubart, T.I. (1992). Buy low and sell high: An investment approach to creativity. *Current Directions in Psychological Science*, *1*(1), 1–5. https://www.jstor.org/stable/20182113.

Torrance, E.P. (2008). *Torrance Tests of Creative Thinking: Figural forms A and B*. Scholastic Testing Service.

Van Buuren, S., Brand, J.P., Groothuis-Oudshoorn, C.G., & Rubin, D.B. (2006). Fully conditional specification in multivariate imputation. *Journal of Statistical Computation and Simulation*, *76*(12), 1049–1064; doi: 10.1080/10629360600810434.

Wang, M., Hao, N., Ku, Y., Grabner, R.H., & Fink, A. (2017). Neural correlates of serial order effect in verbal divergent thinking. *Neuropsychologia*, *99*, 92–100; doi: 10.1016/j.neuropsychologia.2017.03.001.

Willemsen, R.H., de Vink, I.C., Kroesbergen, E.H., & Lazonder, A.W. (2023). *Explaining the Role of Creative Thinking in Children's Scientific Reasoning*. Manuscript submitted for publication.

Willemsen, R.H., Schoevers, E.M., & Kroesbergen, E.H. (2020). The structure of creativity in primary education: an empirical confirmation of the amusement park theory. *The Journal of Creative Behavior*, *54*(4), 857–870; doi: 10.1002/jocb.411.

Zheng, X., Ritter, S.C., & Miller, S.R. (2018). How concept selection tools impact the development of creative ideas in engineering design education. *Journal of Mechanical Design*, *140*(5), 052002; doi: 10.1115/1.4039338.

Robin H. Willemsen, Isabelle C. de Vink, Evelyn H. Kroesbergen, Ard W. Lazonder, Radboud University

*Correspondence concerning this article should be addressed to Robin H. Willemsen, Behavioural Science Institute, Radboud University, Thomas van Aquinostraat 4, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands. E-mail: robin.willemsen@ru.nl

AUTHOR NOTE

Robin Willemsen now works at Stichting Leerplan Ontwikkeling (SLO).

Isabelle de Vink now works at the University of Amsterdam.

This work was supported in part by NRO, the Netherlands Initiative for Education Research [grant number 40.5.18300.014].