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Convergent Thinking Moderates the Relationship between Divergent Thinking and Scientific Creativity

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Creativity plays an important role in human society as well as in individual development, and creativity in the domain of science is a specific form. A body of research had demonstrated the role of divergent thinking in creativity. The role of convergent thinking had also been recognized, but more empirical evidence was needed. To investigate the interaction between convergent and divergent thinking on adolescent scientific creativity, the current study tested 588 high school students. The results showed that convergent thinking interacted with fluency/flexibility of divergent thinking on scientific creativity. In particular, divergent thinking predicted creativity in those high in convergent thinking. Findings suggested a threshold-setting effect of convergent thinking, which meant only when convergent thinking capacity reached a certain level, divergent thinking could play a role in scientific creativity. Implications for future research and educational practice were discussed.

Creativity plays a decisive role in social and individual development (Shi, Cao, Chen, Zhuang, & Qiu, 2017; Shneiderman et al., 2006). Jones and Estes (2015) regarded creativity as “a multidimensional construct that encompasses personal aspects (e.g., traits, behaviors), cognitive processes, and the novelty and usefulness of a final product” (see also Batey, 2012; Caroff & Besancon, 2008; Simonton, 2000; Smith & Ward, 2012). Guilford (1967) pointed out that creative thinking mainly includes divergent thinking and convergent thinking. Divergent thinking is the ability to produce various possible answers or different solutions to one question and is indexed by fluency, flexibility, and originality (Kharkhurin, 2017; Kim, 2006; Michael & Wright, 1989; Wallach & Kogan, 1965). In contrast to divergent thinking, convergent thinking is a form of thought that occurs when individuals use existing knowledge or traditional methods to analyze the given information and obtain the best answer (Gaborra, 2010; Runco, 2004). Such a process had a highly limited scope of search and one tries to obtain one tentative solution for each item (Finke, Ward, & Smith, 1992; Martindale, 2007). In fact, for the process of creation, both two processes may be needed—people do not only have to put forward as many as possible novel ideas, views, or problem solutions, but also need to integrate, evaluate all ideas or problem solutions, and pick out the most suitable, which is especially true for scientific creativity (Howard, Culley, & Dekoninck, 2008; Hu & Adey, 2002; Simonton, 2011, 2015; Webb, Little, Cropper, & Roze, 2017; Zeng, Proctor, & Salvendy, 2010, 2011). Scientific creativity refers to an ability to produce or conceive an original and socially or personally valuable product, based on information provided, and with a well-defined purpose (Boxenbaum, 1991; Hu & Adey, 2002; Lee, Walsh, & Wang, 2015; see also Ayas & Sak, 2014; Sak & Ayas, 2013).

For a long time, literature about creativity has stressed the role of divergent thinking in creative endeavor (Gabriela, 2016; see also Beaty, Smeekens, Silvia, Hodges, & Kane, 2013; Kim, 2008; Long, 2014), and even some studies equate divergent thinking to individual creativity (Baas, De Dreu, & Nijstad, 2008; Silvia, 2008). Some studies have showed that divergent thinking can not only predict the number of achievements (Kim, 2008; Plucker, 1999; Torrance, 1988) but also their quality (Beaty et al., 2013; Fink, Graif, & Neubauer, 2009; Gibson, Folley, & Park, 2009). In contrast, on the role of convergent thinking, views have evolved over years. Classic work by Liam Hudson (as cited in Vernon, 1967) employed measures of both divergent and convergent thinking and found that schoolboys

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interested in sciences tended to be "convergers", which indicated convergent thinking could be positively associated with scientific creativity. Still, some studies argued that convergent thinking was a process of competition, which conflicted with divergent thinking and would impede creativity (for a review, see Cropley, 1967). As more studies came to re-examine the role of convergent thinking in creativity, today it is widely accepted that creativity demands not only divergent thinking but also convergent thinking (Gabriela, 2016; see also Brophy, 1998; Ichino, 2011; Rickards, 1993; Webb et al., 2017). As Cropley (2006) theorized, one of the proposed roles of convergent thinking was to serve as a threshold. Specifically, divergent thinking could be an effective contributor to creativity only when one has a level of convergent thinking above a certain threshold. Recent empirical studies on convergent thinking and creativity varied in measures used and reported inconsistent findings on their relationship (Armstrong, 2012; Beaty, Nusbaum, & Silvia, 2014; Japardi, Bookheimer, Knudsen, Ghahremani, & Bilder, In press). Thus, it remains to be explored as to how convergent thinking acts on creativity, and on scientific creativity in particular.

Both convergent and divergent thinking might be needed to create a scientific creative thought or product. The process of scientific problems solution usually involved three stages (Ayas & Sak, 2014; Hu & Adey, 2002; Lee et al., 2015; Sak & Ayas, 2013): problem generation, method searching, and choice. Problem generation is a process of directed thinking according to certain goals, which can be implemented only when one cannot reach the goal with just existing experience. During the searching stage, divergent thinking plays an essential role as individuals must think in different ways, and find as many effective, feasible, novel, and unique solutions as possible. In the choice stage, individuals would primarily draw on convergent thinking, evaluate and compare various possible solutions, and their outcome according to the goal and finally choose the best way to solve the problem. Besides, previous research showed that, by 15 to 16 years of age, when convergent thinking was developing rapidly, some indices of divergent thinking such as Alternate Uses Tasks reached their highest point before adulthood (Kleibeuker, De Dreu, & Crone, 2013; for a review, see Li, Zhuang, Sun, & Qiu, 2017). There is also evidence showing that scientific creativity in adolescence shares the same nature as that of professional scientists (Hu & Adey, 2002). Thus, adolescence marks the emergence of essential scientific creative thoughts or products (Hu & Adey, 2002), which is meaningful for personal development and cultivation of innovation awareness.

The literature reviewed above showed that divergent thinking was a contributor to creativity, and convergent thinking was also expected to play a role. In fact, divergent thinking is a manifestation of creative potential (Runco & Acar, 2012), and convergent thinking is a powerful ability to transform divergent thinking into creative output (Basadur, 1994). As the three-stage model above suggests, only if people could converge varied potentials into one single outcome, the plentiful novel ideas could lead to actual creation. Thus, it was reasonable to hypothesize that divergent thinking might affect creativity only when one was adequately capable of convergent thinking, especially when it came to scientific creativity. So, the current study examined the role of both convergent and divergent thinking, as well as their interaction in one design. Specifically, convergent thinking was tested as a moderator, and the current study would also test whether it had any direct impact on creativity.

The current study attempted to address the influence of convergent thinking on scientific creativity and focused on its interaction with divergent thinking in adolescence. As findings on convergent thinking and creativity might vary with measurement, the study adopted three measures commonly used today for convergent thinking: Remote Association Test (RAT), Insight problem solving, and graphic convergent thinking.

METHOD

Participants

The sample was comprised of 588 students from one high school (Grades 10 to 12, 406 females and 182 males) in Southwest China. All were native Chinese, with no history of psychiatric illness, and had never participated in studies involving similar tasks. Their age ranged from 14.28 to 19.14 years, and the mean was 16.56 years, SD = 0.70 years. The study was approved by the ethics committees of Peking University. All participants gave written informed consent after a description and an explanation of the study.

Measures

Convergent thinking

Three sub-measures were used: RAT, Insight problem-solving test, and graphic convergent thinking. For RAT, the Chinese version (Jen, Chen, Lien, & Cho, 2004) adapted from the original (Mednick, 1962) was used. The task had two sections, one asking the participants to write a new word related to all three given words; the other asking the participants to write one word that can form a compound word with each of the three words given. This task had 22 terms of words (Bowden & Jung-Beeman, 2003). In Insight problem-solving test, participants were required to solve 13 classic, genuine insight problems, which were adapted from prior published studies (Chiu, Chen, Hsu, Wu, & Cho, 2008; DeYoung, Flanders, & Peterson, 2008; Dow & Mayer, 2004). Graphic convergent thinking was measured with Gestalt Completion Test (GCT) and Snowy Picture Test (SPT). In GCT, 20 pictures which had parts of familiar objects in each one were presented, and then the participants were required to answer what the picture was (Eckstrom, French, Harman, & Dermen, 1976; Kleibeuker et al., 2013). In SPT, for 24 pictures with some familiar objects hidden in snow, participants were asked to find the right objects by neglecting the distraction messages (Eckstrom et al., 1976; Kleibeuker et al., 2013). In all tasks, each item was scored as 1 for correct or 0 for wrong. The raw score on graphic convergent thinking was the sum of GCT and SPT. Then, raw scores on RAT, insight, and graphic thinking were z-standardized, and the three z-scores were added up as the score on convergent thinking, and subsequently analyzed as an independent variable.

Divergent thinking

The tasks involved the Alternate Uses Tasks, Instances Test, and Patterns Test. In the Alternate Uses Task, participants were required to list as many as possible ways of usage of a common item, like a brick (Guilford, 1967; Wallach & Kogan, 1965). In Instances Test, participants were asked to list as many as possible objects with a given characteristic, such as being round (Torrance, 1988; Wallach & Kogan, 1965). In Patterns Test, a simple graph of lines was presented for participants, who were required to list as many as possible meanings represented in the figure (Wallach & Kogan, 1965).

In all three tasks of divergent thinking, the answers were coded in three dimensions: fluency, flexibility, and originality. Fluency referred to the number of reactions or views that are given on each subject. Flexibility was the categories covered by the responses given. Originality was the number of responses that were given by only 1% of the participants. Participants' scores in each dimension from the three tasks were summed as the total in that dimension.

Scientific creativity

The present study was part of a larger project for which all three parts of the Creativity Achievement Questionnaire (CAQ; Carson, Peterson, & Higgins, 2005) were translated into Chinese by Jiang (2016) and administered in adolescents. Items on science in the second part were used as a measure for scientific creativity. To describe how successful one was in the three domains in scientific creativity (invention, scientific discovery, culinary arts), the questionnaire listed eight numbered facts in each of the domains. As with the original version, participants were to check the items that applied to them, and each item was worth the point(s) indicated by the item number. For example, in scientific discovery, if "0. I do not have training or recognized talent in this area" was selected, the participant got a score of 0 in this domain, and it would be skipped; if "2. I have won a prize at a science fair or other local competition" and "4. I have been author or coauthor of a study published in a scientific journal" were selected, the participant's score would be 6. Scores in the three domains were summed for subsequent analyses.

Procedure

In this experiment, the measurement was administered collectively in classes of children. The experimenter first introduced the task to the participants, and then had them sign the informed consent after full understanding. Then, participants completed the tests in the order above in a paper-and-pencil form. In the divergent thinking tasks, the experimenter tried to create a relaxed atmosphere and emphasize "the more the better and errors do not matter." Divergent thinking tasks and graphic convergent thinking tasks had strict time limits, where the divergent thinking tasks were given 3 min each, and the graphics convergent thinking tasks were given 15 s each. After all the experiments were completed, a fine gift was given as compensation.

RESULTS

The analyses were done with SPSS 22 for Windows. The scores of convergent thinking, divergent thinking, and scientific creativity are shown in Table 1. There were significant gender differences in convergent thinking, divergent thinking, and scientific creativity, so gender was used as a control variable in subsequent analyses.

Table 2 presents partial correlations between convergent thinking, divergent thinking, and scientific creativity after controlling for gender. To look at the relationship between convergent and divergent thinking, convergent thinking showed a significant negative correlation with the originality of divergent thinking. Specifically, graphic convergent thinking had a strong significant negative correlation with the fluency, flexibility, and originality of divergent thinking. The three aspects of divergent thinking all showed a significant positive correlation with scientific creativity. The total of convergent thinking showed no correlation with scientific creativity, and only insight had a significant positive correlation with scientific creativity.

Although convergent thinking had no direct correlation with scientific creativity, it was correlated with divergent thinking. Divergent thinking had a significant positive correlation with scientific creativity. As proposed, there was possibly an interaction between convergent thinking and one or more dimensions of divergent thinking on scientific creativity. Next, the interaction between convergent and divergent thinking on scientific creativity was examined with a series of three stepwise regressions. Scientific creativity was the dependent variable, gender was entered into the first step of the regression model, and then convergent thinking and one of the three dimensions of divergent thinking (fluency, flexibility, or originality) were entered into the second step. The last step consisted of the interaction term between the two independent variables in the second. All continuous predictors and moderators were z-standardized.

There was a significant interaction between convergent thinking and fluency of divergent thinking on scientific creativity, $\Delta R^2 = .008$, $\beta = .090$, $t = 2.224$, $p = .027$. Convergent thinking and flexibility of divergent thinking also had an interaction on scientific creativity, $\Delta R^2 = .011$, $\beta = .107$, $t = 2.642$, $p = .008$. No interaction was found between convergent thinking and originality of divergent thinking on scientific creativity, $p = .315$. More statistics are shown in Table S1 of supplementary data.

As fluency and flexibility of divergent thinking were found to interact with convergent thinking, post-hoc simple-slope analyses were conducted with the methods in Dawson (2014). Moderators were set at 1 standard deviation above (high) and below (low) the mean. In all figures, the ends of lines corresponded to 1 standard deviation above (high) and below (low) the mean of predictor. As shown in Figure 1, fluency was significantly associated with scientific creativity only when convergent thinking was high, $B = 0.400$, $p = .001$. The same pattern also applied to the flexibility of divergent thinking. As shown in Figure 2, flexibility was significantly associated with scientific creativity only when convergent thinking was high, $B = 0.396$, $p < .001$.

In order to examine whether there was an interaction between each component of convergent thinking and divergent thinking on scientific creativity, nine more regressions were conducted as above, using RAT, insight, or graphic score instead of the total. For RAT, there was no interaction with fluency, flexibility, or originality of divergent thinking on scientific creativity, $ps > .200$. Insight showed significant interaction with the flexibility of divergent thinking only, $\Delta R^2 = .007$, $\beta = .084$, $t = 2.084$, $p = .038$. As shown in Figure 3, the simple-slope analysis revealed that flexibility was significantly associated with scientific creativity only when insight was high, $B = 0.467$, $p = .001$.

The interaction between graphic convergent thinking and divergent thinking on scientific creativity showed very similar patterns to what was found with the total scores of convergent thinking. Graphic convergent thinking interacted with fluency and flexibility, $\Delta R^2 = .008$, $\beta = .091$, $t = 2.251$, $p = .025$ and $\Delta R^2 = .008$, $\beta = .087$, $t = 2.159$, $p = .031$ respectively, but not originality. As shown in Figures 4 and 5, fluency and flexibility were significantly associated

TABLE 1
Convergent thinking, divergent thinking, and scientific creativity by gender.

	Total(N = *588)*		*Female*(n = *406)*		*Male*(n = *182)*				
	M (SD)	Range	M (SD)	Range	M (SD)	Range	t	p	*Cohen's* d
CT	40.48 (7.68)	17–63	40.03 (7.63)	17–63	41.49 (7.72)	22–60	−2.14	.033	0.190
RAT	13.04 (3.52)	3–21	13.19 (3.59)	3–21	12.70 (3.35)	4–20	1.56	.120	0.141
Insight	7.49 (2.50)	1–13	7.28 (2.52)	1–13	7.97 (2.42)	1–13	−3.10	.002	0.279
Graphic	19.96 (5.42)	7–36	19.56 (5.22)	7–34	2.83 (5.78)	8–36	−2.62	.009	0.231
DT									
fluency	19.68 (7.80)	3–49	20.44 (7.87)	3–49	17.99 (7.39)	4–47	3.56	< .001	0.321
flexibility	15.24 (5.16)	3–37	15.83 (5.19)	3–37	13.92 (4.85)	4–29	4.21	< .001	0.380
originality	3.32 (2.74)	0–19	3.35 (2.68)	0–17	3.26 (2.87)	0–19	0.37	.712	0.032
Scientific Creativity	2.06 (2.33)	0–17	1.79 (2.05)	0–14	2.66 (2.76)	0–17	−3.81	< .001	0.358

TABLE 2
Partial correlations among CT, DT, and Scientific Creativity after controlling for gender.

	1.1	*1.2*	*1.3*	*2.1*	*2.2*	*2.3*	*3*
1. CT	.62***	.47***	.80***	−.07	−.08	−.13**	.04
1.1 RAT		.18***	.14***	.03	.01	−.05	.02
1.2 Insight		–	.09*	.08*	.10*	.04	.12**
1.3 Graphic			–	−.16***	−.17***	−.17***	−.00
2. DT							
2.1 Fluency				–	.92***	.60***	.11**
2.2 Flexibility					–	.54***	.11**
2.3 Originality						–	.16***
3. Scientific Creativity							–

Note. *** $p < .001$, ** $p < .01$, * $p < .05$.

with scientific creativity only when graphic convergent thinking was high, $B = 0.530$, $p < .001$ and $B = 0.484$, $p < .001$, respectively.

Discussion

The present study tested the relationship between convergent thinking, divergent thinking, and adolescent scientific creativity, and extended previous research on creativity by empirically modeling the interaction between convergent and divergent thinking. The results showed that, consistent with previous studies (Beaty et al., 2013; Fink et al., 2009; Gibson et al., 2009), all aspects of divergent thinking showed significant correlation with scientific creativity. Convergent thinking showed no correlation with scientific creativity performance but interacted with fluency/flexibility of divergent thinking on adolescent scientific creativity—only for individuals who performed better in convergent thinking tasks, divergent thinking might predict scientific creativity performance. In sum, convergent thinking is an important ability to actualize creative potential. These findings may promote an understanding of the internal dynamics of creativity.

The major finding of the current study is that the role of individual convergent thinking on creativity is mainly a moderator for divergent thinking, a major predictor of creativity, at least in middle adolescence. This suggested that even if convergent thinking might not act directly on creativity, it might act as a threshold setter, which indicated that convergent thinking was involved in analysis, selection and evaluation in the process of creativity (Gaborra, 2010; Runco, 2004). Though individuals with a low level of convergent thinking might have many novel ideas, they could not effectively select from and integrate these answers. The

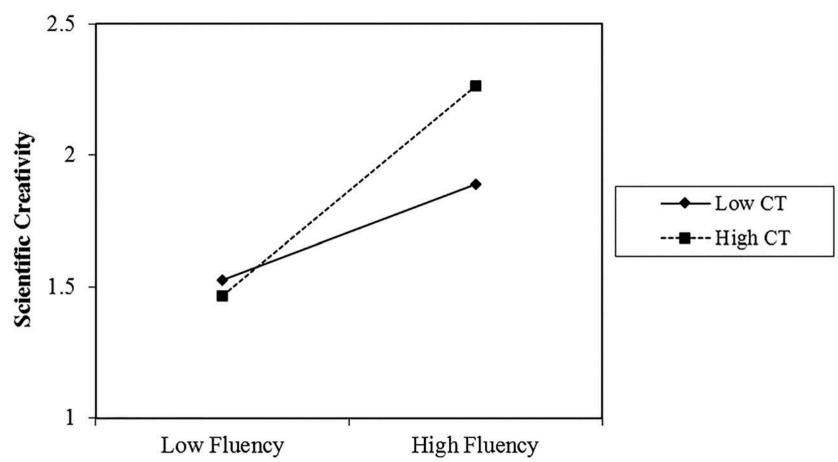

FIGURE 1 Convergent thinking moderated the relationship between fluency and scientific creativity.

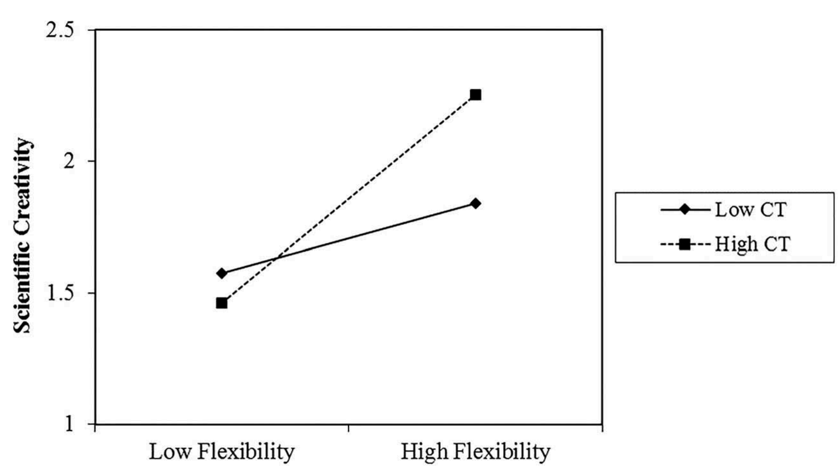

FIGURE 2 Convergent thinking moderated the relationship between flexibility and scientific creativity.

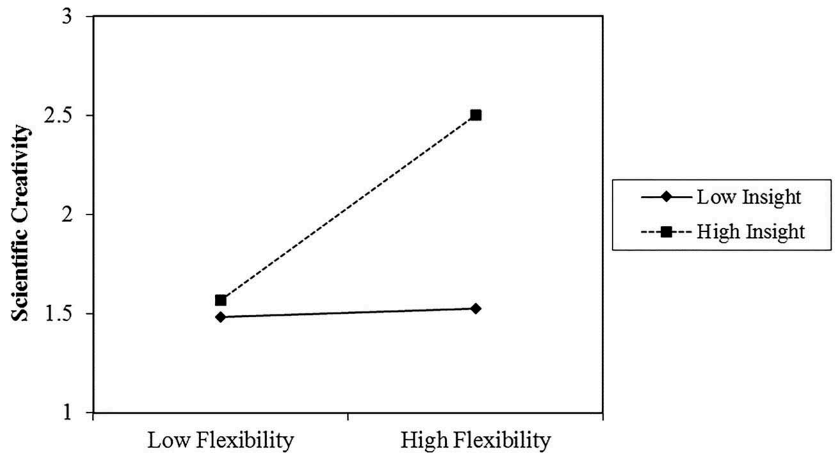

FIGURE 3 Insight moderated the relationship between flexibility and scientific creativity.

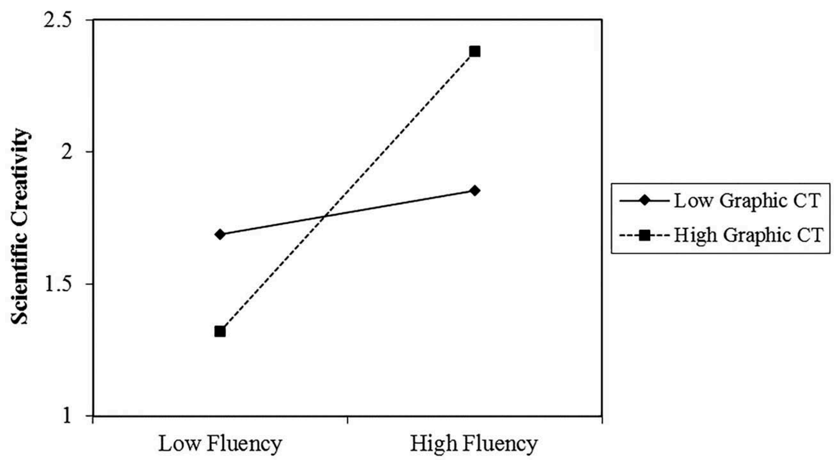

FIGURE 4 Graphic convergent thinking moderated the relationship between fluency and scientific creativity.

most creative output could be expected only when individuals make full use of their ideas produced. When individuals can produce converging ideas, thinking is targeted and it would be more probable to generate the most creative work.

Scientific creativity was different from literary creativity and artistic creativity in that it mainly takes the form of creative problem solving, which is usually conceptualized as involving three stages (Ayas & Sak, 2014; Hu & Adey, 2002; Lee et al., 2015; Sak & Ayas, 2013). The present study showed that convergent thinking is an important ability to actualize the creative potential. The role of convergent thinking in creativity was analogous to a threshold (Cropley, 2006). Only when convergent thinking capacity reaches a certain level, the individual's divergent thinking can play an important role in creation. Also, as Li et al. (2017) suggested, there was a milestone in the development of divergent thinking by ages 15 to 16. Thus, to foster scientific creativity in teenagers, the education community should not only pay attention to the training of divergent thinking but also focus on the training of convergent thinking.

The role of convergent thinking as a direct contributor to scientific creativity is still not quite clear. Findings on the correlation between the RAT task and individual creativity might vary with the domain. There was no stable correlation between it and daily creativity (Armstrong, 2012; Brougher & Rantanen, 2009), but in the only study that explored the creativity achievements of musicians, it was found that there was a significant correlation between the achievement of creativity and the RAT task (Gibson et al., 2009). The present study found no significant correlations between the total of convergent thinking, RAT task or Graphic task, and scientific creativity. These results were similar to previous research. How insight is

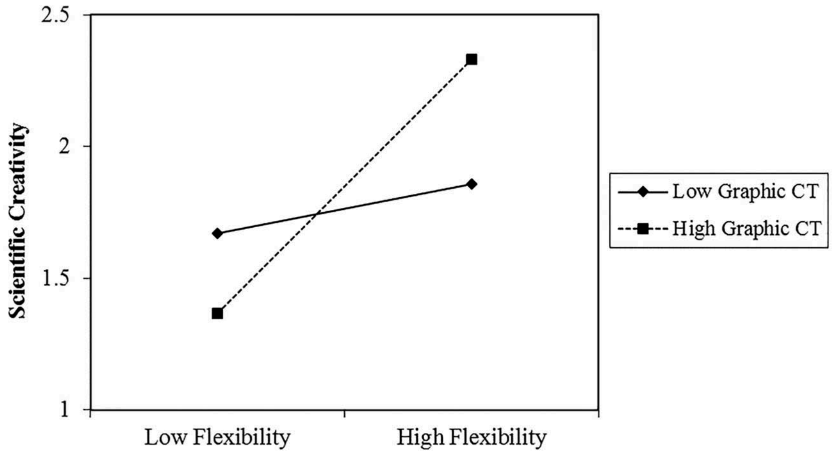

FIGURE 5 Graphic convergent thinking moderated the relationship between flexibility and scientific creativity.

related to creativity might be more complicated. Previous research suggested there was no significant correlation between insight problem solving and individual creativity (Beaty et al., 2014), but the present study found a significant correlation between insight and scientific creativity. During the process of insightful problem solving, individuals not only need to put forward different points of view, but also still need to adopt a targeted strategy of memory searching (Silvia, Beaty, & Nusbaum, 2013). They need to evaluate the scheme to solve the problem, filter (Basadur, 1994; Cropley, 2006) and inhibit ideas that are more prominent but not original (Beaty & Silvia, 2012). These are the processes of convergent thinking and probably involved in scientific creativity. As adolescence shows rapid development in insight, which becomes stable by ages 18 and 19 (Kleibeuker et al., 2013), inconsistencies between the current and previous studies may be partly attributed to the stage of development of the participants.

A major limitation of the present study was with the measurement of creativity. CAQ scores were highly skewed, as in the previous research (e.g., Carson et al., 2005). For adolescents, other instruments such as Creative Behavior Inventory (Dollinger, 2007; Hocevar, 1979) and Creative Activity and Accomplishment Check list (Holland, 1961; Runco, Acar, Kaufman, & Halladay, 2016) should be better. Another drawback was the time limits for divergent thinking tasks. Students should have been instructed to take as much time as needed. Plus, most classes in the high school where the study was conducted had a greater number of girls than boys, which was reflected in the current sample.

Finally, some suggestions for future research are offered. First, the present study focused on high school students and the age range of participants was relatively narrow. Jiang (2016) suggested that the role of convergent thinking might depend on the age group studied. Thus, future research should consider other age groups including adults, to investigate how the patterns of results would vary across ages. Second, the study was an exploration at the behavioral level. Future studies might pay attention to the underlying mechanisms, with an interdisciplinary approach, especially using cognitive neuroscience and genetics. The prefrontal lobe plays an important role in creativity, and its maturation during adolescence might be crucial for development in creativity during this stage (Li et al., 2017). As reviewed in this article, studies have also reported training programs that contributed to both improvements in creative behavior and functional alterations in brain areas associated with cognitive control. Third, as Gabriela (2016) argued, to assess creative potential, shifts between divergent and convergent thinking should be the primary measure or one of the important measures of divergent thinking. Further study should consider this flexible shifting capability.

DISCLOSURE STATEMENT

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SUPPLEMENTARY MATERIAL

Supplemental data for this article can be accessed here.

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