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WEIPING HU
BAOJUN WU
XIAOJUAN JIA
XINFA YI
CHUNYAN DUAN
WINTER MEYER
JAMES C. KAUFMAN

Increasing Students' Scientific Creativity: The "Learn to Think" Intervention Program

ABSTRACT

The "Learn to Think" (LTT) Intervention Program was developed for raising thinking abilities of primary and secondary school students. It has been implemented in more than 300 schools, and more than 200,000 students took part in the experiment over a 10-year span. Several longitudinal intervention studies showed that LTT could promote the development of students' thinking ability, learning motivation, and learning strategy as well as raise academic performance in primary schools. This article describes a study of the influence and the delayed effects of LTT on the scientific creativity of secondary school students. One hundred and seven students were selected from a secondary school, 54 of them participated in the LTT every 2 weeks and the rest had not. The intervention lasted 2 years, and the delayed effect was explored half a year after terminating the intervention. The Scientific Creativity Test for Secondary School Students was used four times from pre-test to delayed post-test. The results indicated that the LTT did promote the development of scientific creativity of secondary school students, and the effects on the scientific creativity were not necessarily immediate, but tended to be long-lasting.

Keywords: intervention, creativity, scientific creativity, "Learn to Think" Intervention Program: Secondary school students.

The "Learn to Think" (LTT) Intervention Program is designed for primary and secondary school students with the intention of raising their thinking ability. It is based on Hu's Thinking Ability Structure Model (TASM) (Hu et al., 2011), Piaget's cognitive development theory, Vygotsky's social construction theory, and Lin and Li's (2003) theory of intelligence. Lin and Li proposed a thinking structure consisting of six components: self-regulation, purpose, materials, process, non-cognitive factors, and qualities and outcomes of thinking. Self-regulation of thinking is the supreme commander of the whole thinking structure, an invisible self underlying the

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visible self. Purpose of thinking refers to the direction and the expected outcome of thinking activities, or the realization of such functions of thinking as adaptation. The materials of thinking can be divided into two categories: concrete and abstract materials. Concrete materials include senses, perceptions, images, etc. The abstract material mainly refers to concepts. Processes of thinking include searching, discriminating, imaging, etc. Non-cognitive factors of thinking include mental factors that are not directly involved in cognitive process, however, have a direct effect on them. Qualities of thinking are the criteria of assessment for the outcome of thinking, including profundity, flexibility, originality, criticism of thinking and agility. Training the qualities of thinking is the breakthrough point in the cultivation of thinking ability.

The LTT program has activities for 1st grade to 8th grade students in primary and secondary schools. Every grade has its specific manual, each including 16 activities covering concrete thinking, abstract thinking, and creative thinking. Secondary school students have different thinking characteristics from primary school students. Hence, the activities of the LTT for secondary school students are different from primary school students. They can be divided into thinking training activities and inquiry activities. Thinking training activities include activities of concrete thinking (image conversion, imagination, space cognition, and association), abstract thinking (comparison, classification, reasoning, generalization, analysis, synthesis, and differentiation) and creative thinking (analogy, reorganization, brainstorm, divergent thinking, breaking the set, and transference). The inquiry activities mainly contain activities of problem finding, problem solving, story inventing, and scientific inquiry. By comparing activities for primary school students, more abstract and creative thinking training activities are designed in textbooks for secondary school students. In each activity, no matter what knowledge, case, and practical exercise arrangement, the combination between student's knowledge and interest and adaptation to realistic life are taken into account, to inspire students' curiosity and desire for knowledge to the maximum extent and absorb them into the activity. In the LTT activities, they have more opportunity to learn basic knowledge, rediscover some laws, face the challenges from creative problem-solving tasks, and awaken potential deep in their brains.

SCIENTIFIC CREATIVITY

There is a general consensus that domain-specific knowledge and skills are major components of creativity. Alexander (1992) and Amabile (1996) emphasized the need for specific domain or discipline-based knowledge and skills for creative thinking. Other researchers (Baer, 1991; Han, 2003; Kaufman & Baer, 2008) have also concluded that creativity is domain-specific. As Barron and Harrington (1981) suggested, more domain-specific aspects of divergent thought may underlie creative productivity. Sternberg (1996) concluded that the correlation coefficient of creativity between different areas is only 0.37.

Science is a very important domain, and there are specific needs of scientific creativity. Almost by definition, scientific research requires creativity in the sense of going beyond existing knowledge and developing new techniques to increase our understanding. However, even at a more mundane level, solving problems in science requires a student to explore his or her repertoire, to imagine a variety of routes to a solution, and frequently to create new combinations of knowledge or novel techniques for a solution. However, despite some research about the creativity of scientists (e.g., Simonton, 2004), few reports about scientific creativity of secondary students have been written.

The concept of creativity, over the years, has proven to be an elusive one to define. Nevertheless, it is possible to detect some common themes. In recent years, many researchers combine two or more aspects of the creative process, creative product, creative person, and creative environment in defining creativity (Amabile, 1996; Csikszentmihalyi, 1988; Sternberg, 1996). Hu and Adey (2002), for secondary school students, have defined scientific creativity as a kind of intellectual trait or ability, potentially producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information. It is concerned with creative science experiments, creative scientific problem finding and solving, and creative scientific activity. Based on the nature of scientific creativity and the previous studies, the three-dimensional Scientific Creativity Model (SSCM) was put forward and *The Scientific Creativity Test for Secondary School Students* was established (Hu & Adey, 2002). The test has been widely used in scientific creativity research and comparisons of the development of creativity between English and Chinese adolescents have been conducted utilizing the test (Hu, Adey, Shen & Lin, 2004).

THE RESEARCH QUESTION

Many scholars believe that creativity can be enhanced through training (Amabile, 1996; Dominowski, 1995; Hennessey, Amabile & Martinage, 1989; Stein, 1974, 1975), and various theories and methods have been proposed for enhancing creativity since the early 1950s that can be categorized into two types. One is an out-of-content (or “bolt-on”, Dewey & Bento, 2009) approach, such as Lipmann’s Philosophy for Children (Lipman, Sharp, & Oscanyan, 1980; Topping & Trickey, 2007a,b), Osborn’s (1953, 1963) brainstorming, Covington, Crutchfield, Davies and Olton’s (1974) Productive Thinking Program, and Buzan’s (2001) mindmapping. The other category is the infusion approach in which the thinking is integrated into one or more school subjects. These include Williams’ (1972) teaching model for promoting creative thinking – which emphasized the application of creative thinking strategies in the classroom, Taylor’s (1967) three-dimensional model to develop students’ creativity, Renzulli’s (1992) theory of training children’s creativity through seeking ideal learning activity, and Adey and Shayer’s (1994) CASE intervention based on Piagetian and Vygotskyan ideas. Meanwhile, Lin and Li (1999) advanced a theory of intelligence and applied it to classroom teaching in various subjects. There’s still a long-standing debate between the two types of approaches to the training of thinking. However, both of the methods have limitations, namely, how to combine the advantages of both and effectively enhance the scientific creativity by intervention are still less explicit.

There are more than 200,000 students from 300 primary and secondary schools taking part in the experiment over 10 years. Several longitudinal intervention studies showed that LTT could promote the development of students' thinking ability, learning motivation, and learning strategy, as well as raise academic performance (Hu et al., 2011). The delay-effects are also significant. However, until now, there has not been a study that has attempted to investigate the effect of LTT on scientific creativity of secondary school students.

LTT claims (Hu et al., 2011) that it accelerates the development of thinking ability, and the cultivation of this ability requires the teaching of thinking methods and the training of thinking quality. These methods must be set within the context of a body of knowledge. With respect to the thinking methods, 35.7% of the activities are designed to train creative thinking, such as divergent thinking, brainstorming, breaking the set, and so on. There is a general consensus that creative thinking is the core of creativity; hence, it seems to be a hypothesis worth pursuing that a program, which can improve creative thinking, may also improve creativity. Science inquiry activities account for 21.4% of the total. Hence, it seems reasonable to seek evidence to support this hypothesis by looking specifically at scientific creativity.

One could hypothesize a number of possible mechanisms by which the LTT might affect scientific creativity: motivation, metacognition, transfer, and a secure atmosphere. Motivation, metacognition, and transfer are three of the five main teaching principles of the LTT program (Hu et al., 2011). Some investigators of creativity believed that motivation counts a great deal (Amabile, 1996; Nicholls, 1972), and many existing studies have suggested that a number of motivations may lead people to be creative and the creativity could occur when the motivation is stimulated moderately (Cangelosi & Schaefer, 1992; Gedo, 1983). LTT pays attention to stimulating students' interest and motivation from choosing activity contents, materials, and activity situations to producing cognitive conflict, teacher-children social construction, and thinking method reflection or transfer. Therefore, this may well be an important route to the development of scientific creativity of students.

Metacognition is the awareness and control of your own thinking. More researchers have stressed the importance of metacognition for improving creative thinking (Perkins & Salomon, 1989). Armbruster (1989) discussed the function of metacognition in the process of creation, and concluded that metacognition plays an important role in creativity. The aim here is to give students practice in monitoring their own thinking, with the teacher initially making their strategies explicit and the learners then internalizing them, making them part of their habitual mode of thinking. At the end of each activity, the students should reflect and summarize the thinking methods, thinking strategies, problem finding and solving methods, and what he/she has learned from the activities. Hence, metacognition may well be an important mechanism for improving the development of scientific creativity.

Another important feature of LTT is transfer or bridging (Hu et al., 2011).In general, an activity in LTT only belongs to a specific domain. The thinking methods and strategies studied in the activity need to be applied and transferred to daily life or to other domains to be able to train the thinking qualities and form general habits of learning. Kaufman and Beghetto (2009), who proposed a Four C model of creativity, believed many people might reach mini-c or little-c creativity in a wide number of areas, although they became more and more specialized and differentiated by the domain as advancing through a career and lifetime. Thus, transfer or bridging in LTT may be another mechanism for accelerating the development of scientific creativity.

Setting up a free, open, democratic, and positive atmosphere is a key factor for the development of students' scientific creativity. In this context, students are not afraid to fail to answer questions, and they will be much more positive and open to obtain knowledge, apply knowledge and solve problems. Creativity flourishes best in a climate where students are allowed to work independently (Anderson et al., 1970), and feel confident that they can take risks without fear of ridicule or censure. In LTT classes, teachers aim to create a free atmosphere in which students think independently, and so it seems reasonable to suppose that such an environment also contributes to the development of scientific creativity.

The main hypothesis was that students who participated in the LTT program demonstrated a higher level of scientific creativity than control group students who did not do LTT.

Subsidiary hypotheses were (a) the LTT had significant effects on students' all aspects of scientific creativity measured; and (b) with respect to the 2-year LTT program and subsequent half a year, effects of LTT on creativity were long-lasting.

METHOD

PARTICIPANTS

The sample for this study was made up of 107 seventh grade students who were 12 years old and up in a secondary school from Shanxi, China. Two classes were chosen for the study. One of the classes was selected as the experimental group, which participated in the "Learn to Think" Intervention Program every 2 weeks. The other class, treated as the control group, did not. There were 27 boys and 27 girls in the experimental group, and 24 boys and 19 girls in the control group. Both groups had the coessential teacher, the same teaching conditions, and other aspects. The experimental group was continuously and effectively trained by professional teachers for 2 years.

MATERIALS

The "Learn to Think" intervention program

The "Learn to Think" Intervention Program was introduced in the former section. Before the experiment, the participating teachers attended a 3-day professional development course and were monitored and mentored by members of the research team. Activities of LTT curriculum are contextualized in physics, chemistry, biology, other disciplines, and daily life experience. For example, the activities in Grade 8 involve eight domains and 15 thinking methods; concretely speaking, there are four thinking methods (observation, classification, divergent thinking, breaking the set) in the domain of chemistry covering two activities, one thinking method (problem finding) in geography involving one activity, three thinking methods (reasoning, space cognition, analogy) in mathematics contained in four activities, and so on. Each activity is delivered in four steps. First, the activity is introduced (i.e., sets up a learning situation via cognitive conflict, which is an effective means to stimulate children to think actively and lead to constructive mental work by students to accommodate their conceptual framework to the new type of thinking necessary). The second step involves facilitating children to observe, think, discuss, and conduct experiments, in the process of which children are encouraged to explore learning methods and strategies by themselves, and stay positive and active in the acquisition of learning. The third step is that children are led to reflect on the process of the activity, how they thought and what they learned. The fourth step involves a broadening activity. That is, students are required to apply and transfer what they learned in the activity to daily life or other domains.

The assignments given to children are progressive in levels of difficulty and complexity. The activities begin from everyday life situations and progress to various subjects. The order of presenting questions is from concrete to abstract and from simple to complex.

The scientific creativity test for secondary school students

The Scientific Creativity Test for Secondary School Students used in this study was designed by Lin (2009), which was revised according to Hu's Scientific Creativity Test (2002) and Torrance's TTCT Torrance, (1965). This test contains five items, which separately correspond to the five dimensions: Creative Scientific Problem Finding (*Item: If you can take a spaceship to travel in the outer space and go to a planet, what scientific questions do you want to research? Please list as many as you can.*), Creative Scientific Product Design (*Item: Please design an apple picking machine. Draw a picture, point out the name and function of each part.*), Creative Scientific Product Improvement (*Item: Below is a stuffed toy dog. Please think up as many possible improvements as you can to this toy dog, making it more useful and more beautiful.*), Creative Scientific Problem Solving (*Item: Please use as many possible methods as you can to divide a square into four equal pieces (same shape).*), and Creative Scientific Imagination (*Item: Below are 30 parallel lines with the same shape. Please on the basis of these parallel lines, draw as many as possible graphics to indicate some scientific staff or phenomenon. Give your drawing a novel and interesting name.*). Considering the following points, the five items are incorporated into this test. First, the test should be limited into the domain of science. Second, in consideration of the materials, two types of materials, including both literal and graphic, were selected into this test. Lastly, the former test (Hu & Adey, 2002) has seven items that are time-consuming and therefore less practical.

The correlation between each item and the whole test is from 0.418 to 0.624 and Cronbach's α coefficient of the whole test is 0.70, which reflect the good reliability and validity. The correlation between literal items and graphic items is 0.286. Past studies also proved this test had good validity. For example, this test was used to explore gender differences on creativity and analyze the influence of different materials (verbal and figure) on creativity (Lin, 2009; Shen & Shi, 2007). And, cross-cultural comparison of adolescents' creativity among China, Japan, UK and Germany was performed (Lin, 2009; Shen & Shi, 2010).

PROCEDURE

The students of the experimental group were instructed using the LTT curriculum once every 2 weeks, and 45 minutes in each session. This was conducted by a member of the research team, whereas the students in the control group were instructed using regular curriculum. During the intervention process, the schoolteachers did not participate in any of the intervention activities except their own teaching. Noting that the extra teaching received by the experimental group amounted only to an extra 16 hours per year compared with a total of over 750 hours of teaching in a school year (about 2%), the LTT will not extensively impact the student's regular schedule and the school's standard teaching methods.

Before the formal experiment, all the participants were measured with the Scientific Creativity Test for Secondary School Students. This test was subsequently used three times during the 2-year intervention; the delayed test was performed half a year after the intervention. One and half years after terminating the intervention, a questionnaire and an interview related to the LTT were conducted. This was intended to tap into what the students in the experimental group thought about the LTT and to examine any changes that may have resulted from the program. Figure 1 displays the detailed experimental design.

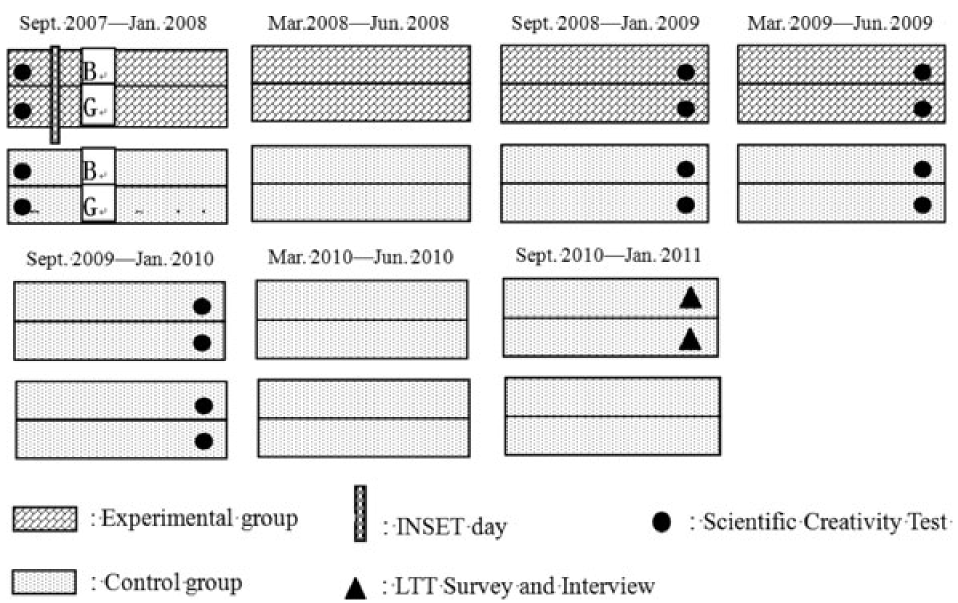

FIGURE 1. The experimental design.

RESULTS

PRE-TEST SCORES

No significant differences were found between the two groups' scientific creativity scores (Table 1) indicating that before the intervention, the two groups started from essentially the same level of scientific creativity.

EFFECTS ON SCIENTIFIC CREATIVITY

All students completed the Scientific Creativity Test three times. Tables 2–7 and Figures 2–7 show the scores of whole test and each dimension between experimental and control groups on each testing occasion.

Effects on overall scientific creativity

Table 2 and Figure 2 show that after one and a half years of the intervention, the whole scientific creativity score of the experimental group was significantly higher than the control group ($p < .01$). Half a year after terminating the intervention, although the decline trend was inevitable, there was still significant difference between experimental group and control group, which increased ($p < .001$) with a large effect size.

Effects on each dimension of scientific creativity

We explored the differences between experimental and control groups on each dimension of scientific creativity test. At the first, repeated Measure ANOVA was used

TABLE 1. Mean Pre-Intervention Scores on Scientific Creativity Test

	Experimental (*M* ± *SD*)	**Control** (*M* ± *SD*)	**t**	**p**
Problem finding	22.45 ± 9.89	25.76 ± 9.11	−1.708	.091
Product design	12.08 ± 6.79	10.93 ± 5.90	.881	.381
Product improvement	14.04 ± 9.18	15.42 ± 9.35	−.738	.462
Problem solving	5.25 ± 2.53	5.42 ± 2.38	−.355	.723
Scientific imagination	12.04 ± 10.97	15.23 ± 7.86	−1.599	.113
Whole test	65.62 ± 26.18	71.58 ± 20.71	−1.213	.228

TABLE 2. Mean Scores on the Whole Scientific Creativity Test for Experimental and Control Groups

	Experimental (*M* ± *SD*)	**Control** (*M* ± *SD*)	**t**	**p**	***d***
Jan. 2009	96.69 ± 32.81	74.46 ± 29.28	3.25	.002**	0.72
Jun. 2009	111.9 ± 29.16	95.50 ± 21.64	3.15	.002**	0.64
Jan. 2010	104.2 ± 25.39	84.43 ± 22.38	3.99	.000***	0.84

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

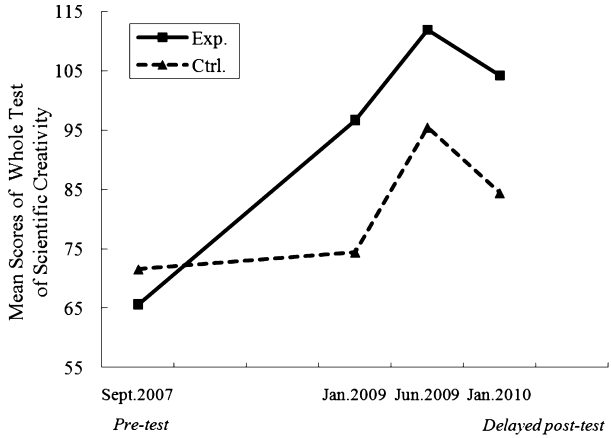

FIGURE 2. The whole scientific creativity test.

to test the main and interaction of time (4), and intervention (2: experimental, control). Results showed: for the dimension of problem finding, there was a significant Time × Intervention interaction, $F(3, 252) = 3.86$, $p < .05$, Partial $\eta^2 = .044$; for product design, there was a significant Time × Intervention interaction, $F(3, 252) = 6.90$, $p < .001$, Partial $\eta^2 = .076$; for product improvement, there was no significant Time × Intervention interaction, $F(3, 252) = 1.07$, $p > .05$, Partial $\eta^2 = .013$; for problem solving, there was a significant Time × Intervention interaction, $F(3, 252) = 2.76$, p .05, Partial $\eta^2 = .030$; for imagination, there was a significant Time × Intervention interaction, $F(3, 252) = 2.99$, $p < .05$, Partial $\eta^2 = .041$.

As is shown in Table 3 and Figure 3, the creative scientific problem finding ability of experimental group always rose steadily. After one and a half years, the problem finding ability of control group appeared to decline, whereas it increased in the experimental group. The experimental group students scored significantly higher on problem finding than the control group on each occasion.

After one and a half years, both the experimental and control groups' creative scientific product design scores declined. However, the experimental group scored increasingly superior to the control group in all subsequent years, and the differences

TABLE 3. Mean Scores on the Scientific Problem Finding for Experimental and Control Groups

	Experimental ($M \pm SD$)	**Control ($M \pm SD$)**	**t**	**p**	***d***
Jan. 2009	24.32 ± 13.71	17.20 ± 11.62	2.64	.010*	0.56
Jun. 2009	28.50 ± 10.74	24.79 ± 7.31	2.09	.039*	0.41
Jan. 2010	28.90 ± 10.98	23.52 ± 8.79	2.66	.009**	0.54

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

were significant with a large effect size, and it continued to expand ($p < .001$) even after terminating the intervention for half a year with a medium effect size. The product design ability of the experimental group appeared to have a leap in development (Table 4 and Figure 4).

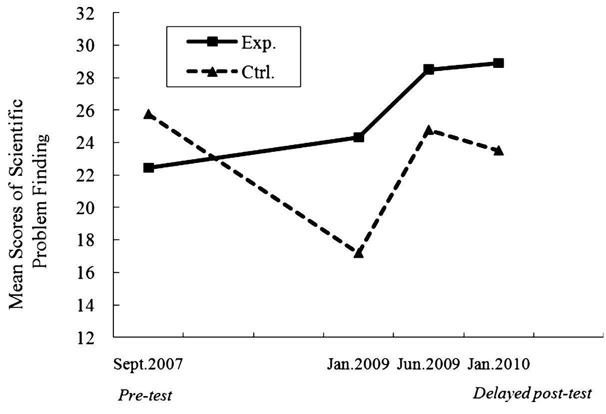

FIGURE 3. Scientific problem finding.

TABLE 4. Mean Scores on the Scientific Product Design for Experimental and Control Groups

	Experimental ($M \pm SD$)	Control ($M \pm SD$)	t	p	*d*
Jan. 2009	10.44 ± 4.66	9.98 ± 4.17	.496	.621	0.10
Jun. 2009	15.87 ± 3.52	10.30 ± 6.62	5.416	.000***	1.06
Jan. 2010	16.98 ± 7.38	11.87 ± 5.92	3.746	.000***	0.77

Note. ***$p < .001$.

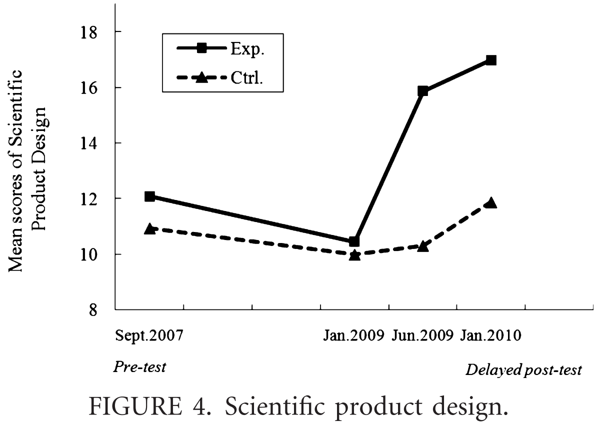

FIGURE 4. Scientific product design.

There were no significant differences on creative scientific product improvement between the experimental and control groups (Table 5 and Figure 5).

As can be seen from Table 6 and Figure 6, after 2 years of intervention, the experimental group students scored significantly higher on creative scientific problem solving than the controls ($p < .01$); and the delayed effect was also significant with a medium effect size. Although both groups' problem-solving ability showed a rising trend after one and a half years, the experimental group appeared to have a durative rising trend, whereas the control group declined.

From Table 7 and Figure 7 we can see that after one and a half years of intervention, the experimental group students scored significantly higher on the creative

TABLE 5. Mean Scores on the Scientific Product Improvement for Experimental and Control Groups

	Experimental ($M \pm SD$)	Control ($M \pm SD$)	t	p	*d*
Jan. 2009	14.10 ± 9.98	12.39 ± 7.68	.900	.371	0.19
Jun. 2009	18.30 ± 9.23	17.91 ± 8.92	.223	.824	0.00
Jan. 2010	16.58 ± 7.03	16.11 ± 7.72	.316	.753	0.06

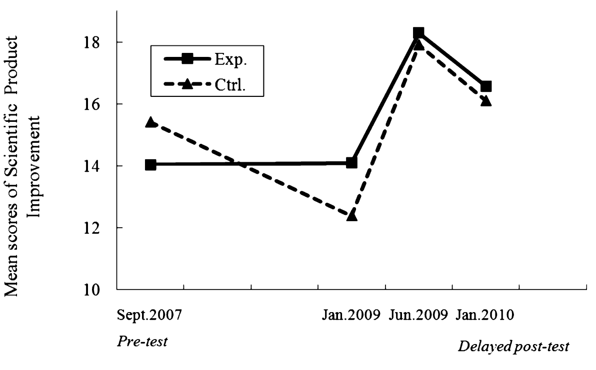

FIGURE 5. Scientific product improvement.

TABLE 6. Mean Scores on the Scientific Problem Solving for Experimental and Control Groups

	Experimental ($M \pm SD$)	Control ($M \pm SD$)	t	p	*d*
Jan. 2009	6.60 ± 5.28	6.54 ± 5.90	.054	.957	0.01
Jun. 2009	7.00 ± 3.30	5.49 ± 2.28	2.748	.007**	0.54
Jan. 2010	8.57 ± 4.88	6.23 ± 3.52	2.746	.007**	0.55

Note. **$p < .01$.

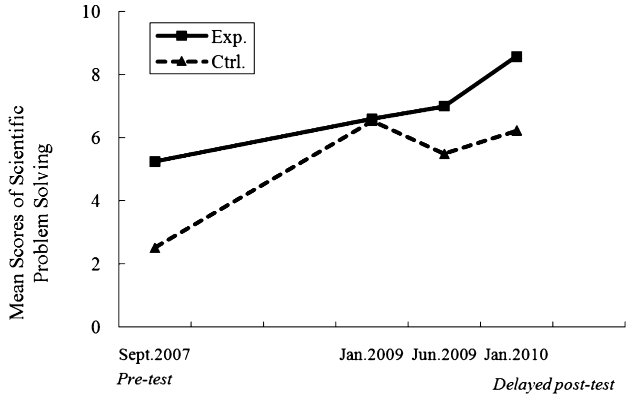

FIGURE 6. Scientific problem solving.

TABLE 7. Mean Scores on the Creative Scientific Imagination for Experimental and Control Groups

	Experimental ($M \pm SD$)	Control ($M \pm SD$)	t	p	*d*
Jan. 2009	37.70 ± 16.92	28.36 ± 12.46	2.926	.004**	0.63
Jun. 2009	41.65 ± 14.54	35.62 ± 12.79	2.166	.033*	0.44
Jan. 2010	31.18 ± 12.84	26.23 ± 10.63	2.066	.042*	0.42

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

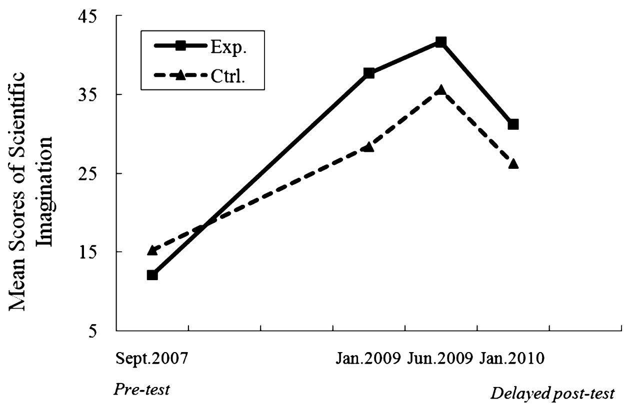

FIGURE 7. Scientific imagination.

scientific imagination than the control group ($p < .01$), and the significant differences continued even after terminating the intervention for half of a year ($p < .05$).

LTT SURVEY AND INTERVIEWS

One and a half years after terminating the intervention, a survey and an interview related to the LTT were conducted, to assess what the experimental students think about the LTT and assess their feelings after following the LTT. The results of the survey and interviews, we can see that many students felt that after attending the LTT, they changed a lot and became more active in class, more independent, more self-reflective, and braver. They could analyze, think or solve problems from different perspectives, they thought learning was more interesting and meaningful, and many methods they had learned in LTT could be applied to other domains or daily life and they often summarized and thought. They usually reflected that the class climate was safe and free, which gave them the courage to speak and fully express their ideas. All these increased their self-confidence and from the group discussion, one idea would stimulate one or more ideas.

Even allowing for a tendency in students to answer positively to questions about their experiences of an innovative curriculum experience, these responses represent an overwhelming endorsement of the subjective experience of students who followed the LTT curriculum.

DISCUSSION

The LTT claims to advance methods for teaching thinking and training scientific creativity. Consistent with the concept of the spiral curriculum (Bruner, 1960), students were taught the methods of thinking scientifically in a hierarchical and circular way to promote the development of their scientific creativity most effectively. The overall level of the scientific creativity of the experimental group was significantly higher than the control group after the LTT intervention, and even half a year after terminating the training, the difference between the two groups was still significant. The result indicates that the LTT did effectively improve and make a long-lasting effect on the development of secondary school students' scientific creativity.

The results of this study fitted well with the findings of Lin, Hu, Adey and Shen's (2003) study. Thus, suggesting that an educational intervention rooted in well-established theories of cognitive development can have long-term and replicable effects on young adolescents' scientific creativity. Explanations for the findings could be as follows.

First, LTT influences students' creative thinking ability directly through the process of teaching students thinking methods. The LTT is designed with some special activities to train creative thinking for enhancing students' creative thinking ability. According to the previous studies, the LTT has shown its positive promoting effect on students' thinking ability (Hu & Zhang, 2009), creative tendency (Li, 2010), creativity (Hu & Yun, 2006), and creative personality (Wu, 2009). Meanwhile, professional knowledge and skills are crucial factors to creativity (Alexander, 1992; Cropley, 1992; Feldhusen, 1995; Mumford, Mobley, Uhiman, Reiter-Palmon & Doares, 1991; Weisberg, 1993); that is the scientific creativity must depend on scientific knowledge and skills. The LTT for the secondary school students combines with the gradually increasing scientific knowledge and skills; hence, it is quite effective to improve the students' scientific creativity thinking.

Second, LTT pays attention to stimulating students' interest and motivation from beginning to end. The motivation was believed to count a great deal on creativity (Golann, 1963; Nicholls, 1972) and the previous studies showed that the LTT could effectively simulate students' learning motivation (Hu & Shan, 2009). With the keen interest, students would take part in the activities more actively, which could maximize the effects of the activities. Students are set in a learning or problem situation via cognitive conflict, which creates a puzzle in the students' minds that is interesting and attackable, to arouse their maximum interests. The conflict is an effective way to make students think actively.

Third, metacognition has claimed to be an essential element of any program, which is successful in improving general thinking skills (Perkins & Salomon, 1989), and Kaufman and Beghetto (in press) have stressed the importance of self-evaluative skills and metacognition. LTT trained, in each activity, students' ability of monitoring and managing their own thinking, reflecting and summarizing the thinking methods, thinking strategies, etc. Meanwhile, the broadening activity in LTT provides chances to use the thinking methods and strategies studied in the activity and then apply and transfer these methods into daily life or other domains. This also effectively accelerates the development of students' scientific creativity.

Fourth, LTT sets up a kind of open, democratic, and positive activity atmosphere, in which the teachers build a democratic, approachable relationship with students (Silberman, 1970). This encourages them to spend more time discussing problems with partners, thinking independently, speaking out their own ideas bravely, and judging others' views, rather than blurting out answers without thinking just to get the teachers' attention. Some environments are believed to be more conductive to the development of creativity (Knapp, 1963; Thistlewaite, 1963), which is helpful for students to think divergently, freely, and to produce more creative products.

Last, many researchers emphasize the importance of the classroom discussion (Murphy, Wilkinson, Soter, Hennessey & Alexander, 2009) and cooperation (Ladd & Dinella, 2009). In the LTT program, team-cooperation is used skillfully during the activities, which can build a special atmosphere for people to think openly and imagine freely, as well as provide opportunities for choice and discovery. The previous research indicated that the LTT had positive effect on students' peer interaction (Mu, 2010). It is effective to compose and collide different thoughts and thinking methods, get more novel and creative products, and then improve students' scientific creativity unconsciously.

Some research has shown that the effect of training on scientific creativity is often delayed (Adey & Shayer, 1994). The LTT improved the students' scientific creativity by metacognitive training, which is also a long-lasting process and its effects on students' scientific creativity appear to have relative stability and continuity. As for the enrichment of the scientific knowledge, the thinking methods learned from the LTT were transferred and used in different subjects by students and they kept on self-monitoring and rethinking during the process. The low tide of creative thinking at age 13 was also shown in this research, which also appeared on several dimensions. However, the LTT was successful in slowing the declining trend and even assisted with causing a rising trend on some dimensions; the smooth transition of experimental group's low tide also showed that LTT could improve the scientific creativity of experimental group.

In summary, our method does not directly teach students thinking processes, but requires students to exert his/her wisdom to realize the requirement of the thinking method, to eventually be able to achieve the level of explaining the thinking process to others. This kind of teaching really mobilizes students' enthusiasm to think, makes them solve problems that they encounter actively, and trains them to transfer the thinking methods they have learned consciously and effectively. The development of the thinking ability in the LTT lays a solid foundation for the improvement of the students' scientific creativity.

According to the research, there appeared to be significant differences on the scientific problem finding, scientific product design, scientific problem solving, and scientific imagination. However, there was no significant difference in scientific product improvement between the experimental and control groups.

The scientific problem-finding ability of the control group shows an obvious declining trend after one and a half years consistent with the result of Hu's research (Hu, Yun, 2006; Hu, 2010); but the experimental group in this dimension showed a rising trend. Chand and Runco (1993) asserted that problem finding is an important and distinct component in the creative process during which the teacher plays an important role (Lowrie, 2002). The LTT teachers are professionally trained and have a good theoretical basis, which makes the training more effective. Meanwhile, the students are treated in a free and open manner (Ciardiello, 1993), and the classroom rules (Meij, 1988) are broken, which helps liberate students' thinking and problem finding ability.

With respect to the scientific product design, the mission of designing a product needs an integration of many abilities (Cross, 1990), and the map of the design process (Maver, 1970) reveals the complexity that makes a successful product design. The LTT stimulated the students' interest and laid the abilities foundation of creative scientific product design very well. Meanwhile, the professional knowledge is identified as the basal and the creative thinking is a crucial factor of product design (Lawson, 2005); as the increasing scientific knowledge and the effective group-work (Paulus & Yang, 2000; Sutton & Hargadon, 1996) during the product design process, the score of the creative scientific product design ascended sharply and the significant difference appears to be long-lasting.

Referring to the improvement of creative scientific problem-solving ability, the reasons may be as follows. During the primary stage, students learn limited amounts of science. In the secondary stage, there are more lessons, deeper content and a wider scope of knowledge in science class; hence, the creative scientific problem-solving ability has been enhanced with an increasing scientific knowledge (Sternberg, 2005). Each activity for the LTT is a procedure on how to solve a problem, which demands focused attention (Vartanian, 2009) that can help accelerate cognitive processing on the task (Mayer, 2006; Weisberg, 1988). Each activity exerts a subtle influence on students' problem-solving ability, and this ability is relatively stable after being enhanced by LTT. Furthermore, LTT helped them to learn to break their former conventional and fixed methods, whereas the new thinking methods and solutions with the increasing scientific knowledge need a concordance; hence, the significant difference did not emerge after one and a half years of invention.

The LTT sets abundant imagination factors with the students' imagination characteristics (Dryden, 2004; Trotman, 2008), and devises many special activities, which are designed to treat training of creative scientific imagination as a core, and requires varying degrees of imagination (Karwowski & Soszynski, 2008). An open and free classroom atmosphere holds fewer restrictions, which can release the inhibitions (Cairns, 2009) and maximizes students' imagination. Besides, the ability of imagination is easier to train than other abilities, and teenagers' imagination develops speedily in this stage. This was enhanced faster by cultivation, and the significant difference was always kept between the experimental and control groups. In all, the LTT appeared to have a promoting effect on the dimensions of scientific creativity, and the effect tended to be long-lasting.

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Weiping Hu, Baojun Wu, Xiaojuan Jia, Xinfa Yi, Chunyan Duan, MOE key laboratory of Modern Teaching Technology, Shaanxi Normal University

Winter Meyer, James C. Kaufman, California State University at San Bernardino

Correspondence concerning this article should be addressed to Weiping Hu, Center for Teacher Professional Ability Development, Shaanxi Normal University, Xi'an, 710062, P. R. China. E-mail: weipinghu@163.com and Dr. James Kaufman, Department of Psychology, California State University at San Bernardino, 5500 University Parkway, San Bernardino, CA 92407, USA. E-mail: jkaufman@csusb.edu

AUTHOR NOTE

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