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Investigation of effective strategies for developing creative science thinking

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ABSTRACT
The purpose of this study was to explore the effectiveness of the creative inquiry-based science teaching on students' creative science thinking and science inquiry performance. A quasi-experimental design consisting one experimental group ($N = 20$) and one comparison group ($N = 24$) with pretest and post-test was conducted. The framework of the intervention focused on potential strategies such as promoting divergent and convergent thinking and providing an open, inquiry-based learning environment that are recommended by the literature. Results revealed that the experimental group students outperformed their counterparts in the comparison group on the performances of science inquiry and convergent thinking. Additional qualitative data analyses from classroom observations and case teacher interviews identified supportive teaching strategies (e.g. facilitating associative thinking, sharing impressive ideas, encouraging evidence-based conclusions, and reviewing and commenting on group presentations) for developing students' creative science thinking.

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KEYWORDS
Convergent thinking; creative science thinking; divergent thinking; science inquiry; scientific creativity

Introduction

There is wide consensus that creativity is the root of providing innovative solutions or novel products that are critical for scientific advancement and economic development. Promoting student creativity has been one of the important goals in education. For instance, the Ministry of Education (2003) has published a government policy document of 'White paper on creative education' intending to collaborate formal and informal educational resources and aiming to nurture creativity for all Taiwanese people. Additionally, the basic law of education enacted by the Ministry of Education (2013) explicitly indicates that creativity is one of the goals in education. Although it is not easy to define creativity, especially in the context of science, it is believed that the cognitive operations (i.e. divergent and convergent thinking) required for creativity can be developed through well-designed programmes (Scott, Leritz, & Mumford, 2004). Bull, Montgomery, and Baloche (1995) recommended that motivational and social interactional approaches could also be supportive in promoting student performance of creativity. Insights

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gained from the above literature revealed that designing theory-based intervention to develop creativity performance and examining its effectiveness are critical and feasible. However, what remains relatively poorly understood are the key characteristics and details of effective interventions that influenced the success of developing student creativity performance. Recently by using the Torrance Tests of Creative Thinking, Yoon, Woo, Treagust, and Chandrasegaran's (2015) study revealed that the use of a problem-based learning approach in a chemistry laboratory course significantly promoted students' creative thinking abilities. The initial fruitful results of their study on general creative thinking abilities inspire us to further explore how content-specific (i.e. science) creative thinking can be developed. In addition, Kind and Kind (2007) recommended further research on developing specific aspects of creativity tests, and teaching materials were needed to enable a better understanding of what should be done to achieve increased scientific creativity. Therefore, this study explored the effectiveness of an intervention focused on enhancing creative science thinking and science inquiry competency through the integration of the aforementioned cognitive, motivational, and social interactional approaches of science teaching.

Theoretical perspective

This study's design of an intervention for stimulating students' creative efforts was inspired by the potential effectiveness of a cognitive approach (Scott et al., 2004), a motivational and social climate approach (Bull et al., 1995), and the essential element of 'engaging in critique and evaluation' for constructing new knowledge and learning science (National Research Council, 2013). In their meta-analysis of 70 studies, Scott et al. (2004) found that successful interventions tended to be based on a cognitive framework. Learning processes stressing the cognitive activities of problem identification, idea generation, and conceptual combination are significantly related to study success. They further proposed that 'the success of creativity training can be attributed to developing and providing guidance concerning the application of requisite cognitive capacities' (Scott et al., 2004, p. 382).

In addition to the cognitive approach, Bull et al. (1995) posited the importance of social climate in motivating students' creative efforts. They argue that providing a social climate with a variety of opportunities of open exploration and allowing students to feel free and safe to explore their creativity potential in turn promote curiosity, inquisitiveness, insight, and innovation.

Following the publication of National Science Education Standards (1996), the National Research Council proposed 'A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas' (2013). In the framework, important practices such as developing explorations and solutions along with engaging in critique and evaluation have been emphasised as essential elements in the content of science education. The emphasis of critique and evaluation is consistent with the advocate of social constructivism (Driver, Leach, & Millar, 1996) and training of reflective ability (Lee & Hutchison, 1998). With these learning opportunities, students are encouraged to construct knowledge and arguments, present ideas and findings, and discuss and debate justifications and assertions.

The combination of the above cognitive approach and motivational and social climate approach, and the role of critique and evaluation in science practices enable the authors to hypothesise that students' creative efforts could be better developed when they are engaged in learning science. Additionally, the following related literature guided the development and design of the study.

Scientific creativity

In essence, scientific creativity is recognised as a way of problem-solving leading to exceptional accomplishments and productivity (Esquivel, 1995) and containing major components of domain-specific and domain general knowledge, science process skills, divergent thinking (Heller, 2007; Hu & Adey, 2002; Klahr, 2000), and convergent thinking (Mukhopadhyay & Sen, 2013; Runco & Acar, 2012; Sternberg, 2006). In defining the new framework for K-12 science education, the National Research Council (2013) states:

> One helpful way of understanding the practices of scientists and engineers is to frame them as work that is done in three spheres of activity … the dominant activity is investigation and empirical inquiry. In the second, the essence of work is the construction of explorations or designs using reasoning, creative thinking, and models. (p. 45)

According to the above statements, creative thinking such as divergent thinking or convergent thinking is one of the critical essentials when scientists, engineers, or students are engaged in constructing explanations or developing solutions. Thus, to provide empirical evidence for the National Research Council's statement and in response to the Taiwanese Ministry of Education's (2003, 2013) call for developing student creativity, Yang, Lin, Hong, and Lin (2016) examined and enlightened the significant relationship between students' creative thinking and science inquiry performance. This current study seeks to extend the understanding about the potential impact of inquiry-based science teaching on students' creative science thinking.

Teaching for creativity and creative teaching

The distinction between 'teaching for creativity' and 'creative teaching' has been properly identified by the National Advisory Committee on Creative & Cultural Education (NACCCE) (1999). 'Teaching for creativity' attempts to make creativity a learning outcome, while 'creative teaching' is looking for using imaginative approaches to make learning more interesting, exciting, and effective (National Advisory Committee on Creative & Cultural Education, 1999). Kind and Kind (2007) reviewed the existing science education literature to contrast that creative teaching is generally associated with open-ended, multiple-solution, student-oriented, exploratory, and group-based learning opportunities, while traditional expository teaching simply focuses on closed problems, teacher-oriented and closed-ended tasks, and individual work. They argue that if science educators want creativity to be more than a label, it is necessary to focus on the ends or how best to teach for creativity rather than just the general means of creative teaching. Further research on developing specific aspects of creativity tests and teaching materials is needed to enable us better understand what we should do to achieve increased scientific creativity.

Science inquiry

The importance of science inquiry has been emphasised in national curriculum or national science education standards (National Research Council, 1996, 2000). Teachers are encouraged to engage students in authentic scientific investigations of making hypotheses, designing experimental procedures, and interpreting data and evidence rather than focusing narrowly on the learning of content knowledge and concepts (Morrison, 2014). Recently, important practices such as engaging students in critique and evaluation have been emphasised in K-12 science education (National Research Council, 2013) to encourage students to work together like scientists and engineers in developing novel ways of data collection and evidence-based arguments, identifying weaknesses and limitations of their arguments, and refining their experimental designs or explanations. Taylor, Jones, Broadwell, and Oppewal (2008) also concluded that the majority of scientists and science teachers who participated in their semi-structured interview study held a strong belief that students should experience the joyful creativity of doing open-ended science inquiry. Unfortunately, the teachers in their study experienced frustration about trying to teach science as inquiry. DeHaan (2011) pointed out that in addition to the emphasis on the higher-order thinking skills of analysis, synthesis, and critical reasoning when students are engaged in science inquiry activities, they should be encouraged to search for novel problem solutions through the extended exercise of associated thought (i.e. divergent thinking). The gap between the goal set by the framework for K-12 science education (National Research Council, 2013) and the typical status of science teaching practices reveals and justifies that developing teaching strategies for higher-order creative science thinking (Kind & Kind, 2007) and teacher professional development (Lin, Hong, Yang, & Lee, 2013; Liu & Lin, 2014) have become important aspects of science education. However, the existing domestic and international literature has limited understanding about how or if the practices of science inquiry have any potential to enhance students' creative science thinking.

Therefore, this study is intended to develop theory-based teaching practices and examine its effects of promoting student scientific creativity especially on creative science thinking. The following research questions are explored in this study:

(1) What is the impact of creative inquiry-based science teaching (CIST) on students' creative science thinking and science inquiry performance?
(2) What teaching practices are supportive of students' reflection on divergent and convergent thinking?

Method

In order to explore the impact of CIST on students' creative science thinking, a two-group quasi-experimental design consisting of an experimental group and a comparison group with pretest and post-test was employed. In addition, a case study approach was used to answer 'what' teaching practices were effective and 'how' they were used to support student reflection on divergent and convergent thinking. Thus, direct observations of the case teacher's CIST practices during the whole semester were conducted. More details regarding the research method are described in the following paragraphs.

Participants and settings

This study took place in a typical elementary school located in Kaohsiung city, Taiwan. Although the student population of the selected school was less than 1000, the students came from a diverse socio-economic background. An experienced and award-winning inquiry-based science teacher, Wang and his 44 students from two classes were asked to participate in this quasi-experimental study. Wang has 10.5 years of teaching experience and has been involved in inquiry-based science teaching for four years. He has been selected as a science major counsellor of the city-wide compulsory education advisory group, an honourable job in Kaohsiung. Furthermore, Wang also took part in developing contextualised inquiry-based test items in the past two years and he has become an award-winning teacher. His designed test items were chosen and uploaded on the Internet as free-choice online tests which elementary students were encouraged to respond freely in school holidays. Wang's classroom teaching practices were observed before the study was conducted and confirmed as inquiry-oriented, where students are encouraged to making hypotheses, providing ideas for solving problems, designing investigation procedures, and presenting and discussing experimental findings.

Wang was in charge of teaching science subject for all 5th-grade students. Hence, one class was randomly selected as the experimental group ($N = 20$). In order to avoid contamination of teaching intervention, another class of 6th-grade students ($N = 24$) taught by a similar background teacher with Wang was selected as the comparison group. It was assumed that the sixth graders who have one more year of science learning experience would be more qualified to serve as the comparison group than the fifth graders.

Instruments

Two instruments – the science inquiry test and the scientific creativity test that have been previously validated with satisfactory reliability and validity (Yang et al., 2016) – were used in this study.

Science inquiry test

This instrument was composed of seven open-ended inquiry (O-inquiry) test items and 24 multiple-choice inquiry (M-inquiry) test items. The O-inquiry test was derived from the frame structure used by Cuevas, Lee, and Hart (2005). Students were asked to respond in a contextual problem situation of designing an experiment to investigate the efficiency of water absorption of two different brands of paper towel used in a kitchen. Following the explanation of the problem situation, seven test items were posed to assess student competencies of identifying the research question (2 points), making a hypothesis (2 points), designing the experimental procedure (3 points), planning the required equipment and material (2 points), collecting data and evidence (3 points), drawing evidence-based conclusion (2 points), and constructing conceptual understanding (3 points). The scoring rubrics awarded full credit to a reasonable and complete statement; partial credit was given to reasonable but incomplete statements; and zero credit was assigned to a wrong answer or no answer. Thus, the possible total credit of the seven O-inquiry test items was 17 points. The validity and reliability of the O-inquiry assessment were established in a previous study. The internal consistency Cronbach α of the O-inquiry assessment was .72 for the validation sample (Yang et al., 2016). In this study, two researchers separately used the above-mentioned scoring rubric and criteria on the grading process to ensure getting a reliable result. The inter-rater reliability of the O-inquiry on these seven items ranged from 0.89 to 1.00, $p < .001$. The pretest and post-test internal consistency for this study revealed a Cronbach α of .62 and .80, respectively.

The M-inquiry test was composed of 24 multiple-choice items which were distributed in the following five main constructs, and the number of items for each construct is stated in parentheses: identifying the research question (4), making a hypothesis (4), planning the investigation (8), reporting the result (4), and drawing conclusion (4). The following sample item is a typical example of assessing student competency of identifying the research question (Yang et al., 2016, p.11).

> Mary is interested in investigating the behavior of local endangered fishes. She designed an experiment. At first, she puts dark color stones on the left sides of an aquarium while the white color stones were on the other side. She prepared five local endangered fishes and put it into the aquarium once at a time; she recorded the frequency counts while the observed fish stays in a specific area that was lasted for longer than 30 seconds. Each fish was observed for 10 minutes. According to the above design, which one of the following four options was Mary's research question? (*: correct answer)

(1) How frequently would the local endangered fishes stay in the dark stone area?
(2) How long was the local endangered fish staying in the dark stone area?
(3) Does the local endangered fish prefer to stay in the dark stone area or the white stone area?*
(4) Do local endangered fishes like to stay in the stone area?

The validity and reliability of the M-inquiry assessment were established in a previous study. The internal consistency Cronbach α of M-inquiry was .72 for the validation sample. The pretest and post-test internal consistency Cronbach α for the M-inquiry items in this study were .70 and .73, respectively.

Scientific creativity test

This assessment contained nine open-ended test items with the constructs of divergent thinking and convergent thinking. Divergent thinking items (i.e. items one to seven (one sample test item asked students to '*Assuming that if there were no sun, what would the world be like? For example, we would not be able to see the moon*')) were modified from Hu and Adey (2002). Students were encouraged to provide as many answers as possible. The convergent thinking items (i.e. questions eight and nine) were developed and validated by Yang et al. (2016) in a previous cross-sectional study from grade 3 to grade 6 students. One sample test item of convergent thinking is presented as follows:

> *Students were asked to* 'develop strategies of tying two downward strings together with one end of the two strings fixed on the ceiling of a room. The challenge is that the two strings are separated too far to be reached by hands. To solve the problem, students are given tools of chair, rubber band, glass balls, glass jar, and hand plier'. (Yang et al., 2016, p. 18)

The overall discrimination indices of these items ranged from .28 to .99, difficulty indices varied from .14 to .50, and internal consistency was .89 (Cronbach's α). Meanwhile, the Cronbach α of this assessment was .56 in the pretest and .70 in the post-test.

CIST intervention

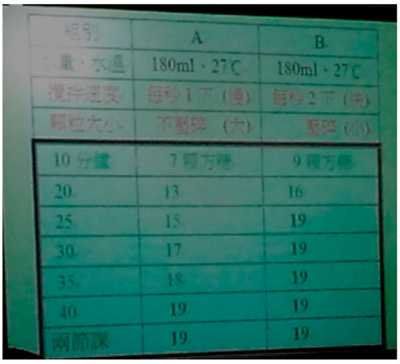
The case study teacher, Wang, was instructed to conduct the intervention in one session of a 1-hour workshop and three 1-hour discussions. The workshop was focused on the introduction of creative science thinking instruction. Professional journal articles explaining the framework of creative science thinking (i.e. divergent thinking and convergent thinking; DeHaan, 2011; Meyer & Lederman, 2013) and sample teaching lessons (e.g. electrical circuit lesson) were used as discussion materials. Research team members and Wang discussed the key components of creative science thinking, which were less emphasised in previous studies. The CIST put emphasis on creative science thinking (i.e. divergent and convergent) and inquiry-based science teaching. Then, Wang started on designing his own instructional activities, which were based upon units in a prescribed science textbook. Basically, four instructional units (i.e. aqueous solution, force, astronomy, and combustion) were designed and used in the intervention.

Three round-table discussions were held in the case study school monthly. Research team members and Wang discussed effective teaching strategies, which were related to creative science thinking. Finally, four teaching strategies emerged and were emphasised in the intervention as encouraging students' learning from peers, encouraging students to think deeply before responding to teacher's questions, praising students' unique ideas in class, and providing openness within the learning environment.

In the CIST intervention, the framework of science inquiry teaching was focused on questioning, planning, implementing, concluding, and reporting (Cuevas et al., 2005), while the framework of promoting creative science thinking was focused on divergent thinking and convergent thinking. Students were encouraged to propose multiple research methods to solve the ill-structured problem (i.e. practice of divergent thinking) through a small group discussion. Each group was encouraged to evaluate potential strengths and weaknesses of their group members' proposals and make a group consensus to select the best proposal for further exploration. Finally, students were asked to identify the key independent variable influencing the result of their experiment through a group discussion (i.e. practice of convergent thinking). For instance, students were asked to propose several crucial factors which might be affecting sugar's dissolution rate. Each group was encouraged to present their prediction (e.g. students of group 6 mentioned that sugar's size will affect sugar's dissolution rate), and then Wang showed some related experimental data of sugar dissolution rate which were done by former senior students (Figure 1; experimental results of the amount of sugar dissolved in 180 ml water along with time on two equal amounts but different sizes of sugar A and B). Finally, after students reviewed the variation in results between experiments for sugar A and sugar B, they were encouraged to identify the main factors affecting the sugar dissolution rate.

Data collection

The experimental group students participated in 16-week CIST lessons, while the comparison group students attended the same time of instruction with regular and typical science teaching. For the collection of quantitative data, both groups responded to the science inquiry test and scientific creativity test for the pretest and repeated post-test. Testing time of each instrument was spanned 80 and 40 minutes, respectively.



Experiment	A	B
Amount of water, Temperature	180ml, 27℃	180ml, 27℃
stirring speed	1 circle per second	2 circle per second
Sugar's size(equal amount)	big pieces	small pieces
Time of observation:	**Number of cubes dissolved:**	**Number of cubes dissolved:**
10 minutes	7 cubes	9 cubes
20 minutes	13 cubes	16 cubes
25 minutes	15 cubes	19 cubes
30 minutes	17 cubes	19 cubes
35 minutes	18 cubes	19 cubes
40 minutes	19 cubes	19 cubes
80 minutes	19 cubes	19 cubes

Figure 1. Former senior students' experimental data regarding to the amount of sugar (cube) dissolution in 180 ml of water.

For the purpose of collecting qualitative data, researchers observed video-recorded case teacher teaching practices for three periods per week. In total, 48 periods of teaching practices were collected. Wang was interviewed to elaborate or justify the rationale of his teaching practices at the end of each classroom observation. Continuing formal and informal interviews, researchers' on-site visit field notes, students' worksheets, and teacher's lesson plan were used to triangulate and consolidate what teaching methods were used to support creative science thinking.

Data analysis

A mixed-method approach was used for the data analysis, which combines both quantitative and qualitative methods (Tashakkori & Teddlie, 2010). Analysis of covariance (ANCOVA) was conducted for assessing the differences between groups on science inquiry performance and creative science thinking. The use of ANCOVA allows us to statistically adjust the post-test means of dependent variables by the group means of the covariate (i.e. pretest means of the experimental and comparison groups). In other words, ANCOVA decomposes the variance in the post-test means into variance explained by the pretest means. In addition, discourse analysis (Gee, 2011) was used to analyse and interpret each CIST lesson video-transcript. Structures (e.g. lines and stanzas) were utilised to identify the themes of teaching practices that are focused on supporting students' reflection on divergent thinking and convergent thinking. Carving-up process was done by two researchers who examined and re-examined all data until they reached consensus in organising and grouping stanzas. Consequently, themes of teaching practices emerged from the above procedure.

Results

Quantitative: What is the impact of CIST on students' creative science thinking and science inquiry performance?

The ANCOVA results and descriptive statistics of the mean scores, standard deviations, standard errors, and *F* values of the two groups' comparison on creative science thinking, divergent thinking, convergent thinking, and science inquiry performance are presented in Table 1. The experimental group's adjusted post-test mean scores of 29.27, 27.98, 1.35, and 19.05 for the above four dependent variables were all higher than the comparison group's matching adjusted post-test mean scores of 21.37, 20.60, 0.73, and 15.63. The ANCOVA results revealed that the experimental group students significantly outperformed their counterparts on the performances of science inquiry ($F = 5.186$, $p = .028$, $ES = .120$) and convergent thinking ($F = 4.259$, $p = .046$, $ES = .101$). Additional paired-sample *t*-test results revealed that the experimental group students made a significant progress on performances of science inquiry ($t = 2.468$, $p = .025$) and divergent thinking ($t = 2.436$, $p = .027$), while the comparison group students showed no significant changes on these assessments.

Qualitative: What teaching practices are supportive of students' reflection on creative science thinking?

The second research question of this study was to explore what teaching practices were used by the case teacher having the potential to support students' reflection on divergent thinking and convergent thinking. The data included the case study teacher's oral reflections after each classroom practice, two researchers' field notes of observation, and transcripts of video-taped teaching practices. We presented the findings according to two major aspects: divergent thinking and convergent thinking. Table 2 shows the summary of coding results. The main supporting teaching practices of divergent thinking are 'facilitating associative thinking' and 'sharing impressive ideas', while the teaching practices of 'Encouraging evidence-based conclusion' and 'Reviewing and commenting on group presentation' are supportive to the development of convergent thinking.

Facilitating associative thinking. Student–student interactions or student–teacher interactions were labelled as a main teaching practice to facilitate student associative thinking (DeHaan, 2011; Meyer & Lederman, 2013). In this study, we further found that the strategy of challenging students to answer was a frequently used teaching practice for facilitating students' associative thinking. Students were encouraged to observe the phenomena from multiple aspects (i.e. flexibility) rather than focusing on relevant responses in one single aspect (i.e. fluency).

For instance, Wang posed an ill-structured question and asked students working in small groups to identify what were the differences between white solid A and B when the two substances were separately put into two small bottles containing the same amount of water. In the beginning, students only focused on the appearance of white solid A and B. As Wang asked the students to elaborate their answer, the students focused on the changes in sugar (i.e. solute), water (i.e. solvent), and sugar solution (i.e. aqueous). Thus, challenging or questioning was an effective teaching practice in facilitating students' divergent thinking. The following excerpt provides an example of challenging

Table 1. Result of ANCOVAs of students' creative science thinking and science inquiry performance between experimental and comparison groups.

Construct	Groups	*N*	Pretest			Post-test			Adjusted post-test		*F*	*P*	*ES*(η^{2a})
			M	*SD*	*SE*	*M*	*SD*	*SE*	*M*	*SE*			
Creative Science thinking[b]	Exp.	17	21.62	13.73	3.33	30.21	18.97	4.60	29.27	3.03	3.961	.054	.094
	Com.	24	19.23	9.91	2.02	20.71	10.42	2.13	21.37	2.55			
Divergent thinking[b]	Exp.	17	20.59	13.11	3.18	28.82	18.21	4.42	27.98	2.92	3.727	.061	.089
	Com.	24	18.38	10.07	2.06	20.00	10.06	2.05	20.60	2.45			
Convergent thinking[b]	Exp.	17	1.03	1.21	0.29	1.38	1.23	0.30	1.35	0.23	4.259	.046	.101
	Com.	24	0.85	0.91	0.19	0.71	0.76	0.16	0.73	0.20			
Science Inquiry[b]	Exp.	17	16.82	6.00	1.46	20.35	8.15	1.98	19.05	1.14	5.186	.028	.120
	Com.	24	14.21	4.76	0.97	14.71	4.82	0.98	15.63	0.95			

Note: $^a\eta^2$ = eta-squared effect size (Small 0.01; medium 0.059; large: 0.138) (Cohen, 1988)).
[b]Scores of creative science thinking (0–70 points; 9 items); divergent thinking (0–66 points; 7 items); convergent thinking (0–4 points; 2 items); science inquiry performance (i.e. O-inquiry and M-inquiry: 0–41 points; 7 open-ended items and 24 multiple-choice items).

Table 2. Teaching practices that are supportive of students' creative science thinking in divergent and convergent thinking.

Construct	Category	Description
Divergent thinking	Facilitating associative thinking	Challenging students' single-dimension answer through questioning. Inspiring students to identify key variables from different aspects in conducting their experiments.
	Sharing impressive ideas	Praising students' unique ideas in class. Sharing individual or other classes' impressive experimental design.
Convergent thinking	Encouraging evidence-based conclusion	Encouraging students to practise drawing a compelling conclusion with supportive data and evidence.
	Reviewing and commenting on group presentation	Leading students in reviewing other groups' presentation and making some suggestions.

students' single aspect answer by questioning on the instructional unit of an aqueous solution.

T: Well … what data do you have that allows you to indicate [white solid] A is dissolved, but not B. [*Wang posed an ill-structured question*]
S6: B is stone
T: Why do you think B is stone? *[Wang challenged students' response*]
S6: because it does not seem to be dissolved [in water]。
T: Why do you think it seems not to be dissolving? What do you observe [and] what [evidences do you have to] help you make that judgment [*Wang challenged students' response*]
T: OK, guys. What do you observe [and] what [evidences do you have to] help you make that judgment?
S22: Solid A become smaller, but not B [*students were aware of solid A became smaller; it could be stated as the first aspect finding, which was regarding to solute]*
T: A has become smaller, but not B. What else?
S8: Something was floating up? [*students were aware of sugar dissolving into water; it could be stated as the second aspect finding, which was regarding to solvent*]
T: Floating … ? Which part was floating up?
T: Solid A was disappeared … … rise up your hand [*students have discovered something new to them*]
S8: Sir, our solid A became very small.
T: Well, what do you want to say, would you like to elaborate a little bit?
S13: It's felt sticky at the bottom of the bottle A [*students were aware of sugar dissolving into water and became as a solution; it could be stated as the third aspect finding, which was regarding solution]*

Similarly, another activity which was regarding student–teacher interaction inspired students to identify key variables from different aspects of conducting their experiment. The excerpts below show how Wang inspired students to propose several factors which may cause iron to rust (such as blowing wind, sunlight, rain, acid rain, and saltwater). In addition, Wang tried to inspire students to figure out the key variables behind the aforementioned natural phenomenon. For instance, students thought iron exposure to rain as a reason for iron rusting. Wang then lead the students to discuss and clarified that the key variable is 'water' rather than 'rainy day'. The following excerpts provide the details of the interaction between Wang and his students.

Excerpt A:

T: Well … what do you think … Which situations were caused bicycle, iron handrail or window with iron material getting in rust easily …
S7: Dipped in water..
T: What else …
T: In which situation will cause bicycle, iron handrail or window with iron getting in rust easily. [*Teacher repeated again the key question*]
S22: 'air'.. .a lot of air
T: well … that's true … but in a real situation, we can't withdraw all the iron material from the air. [*Teacher reminded students that experiment design must link to the real situation; we live in the earth, we need air to survive]*
T: Well … in which situation will cause the bicycle to get rust easily.
S?: Riding to wetland …
T: So … it means that we must ride our bicycle to hang around, right?
T: So … in which places will cause the bicycle to get rust easily?
SA: Outdoor …
T: Beside the factor of 'air' in outdoor, what else …
SA: Wind blow … *[Wang writes down the phrase of wind blow on blackboard]*
SA: Sun exposed.. *[Wang writes down the word of sunlight on blackboard]*
SA: Be exposed in the rain … *[Wang writes down the phrase of being exposed to the rain on blackboard]*

Excerpt B:

T: Well … as considering the phenomena of wind blowing that will inspire you associate with the factor of air; then how about the phenomena of exposing to sunlight?
SA: Light … *[Wang write down the word of light on blackboard]*
T: What else..
SA: Heat … *[Wang write down the word of heat on blackboard]*
T: What factor is related to blowing wind?
SA: Air.. [Wang write down the word of air on blackboard]

Excerpt A indicated that Wang facilitated students to propose several factors related to iron getting in rust (i.e. divergent thinking) on the instructional unit of oxidation. Excerpt B indicated that Wang tried to inspire students to identify the key variable from each phenomenon (as shown in Figure 2).

Sharing impressive ideas. Sharing the experimental design of others is an alternative peer learning strategy. As teacher shared some unusual or unique ideas which were designed by peers, students could be inspired. In this case, Wang always shared some novel design with the experimental group students. For instance, in one lesson, students were asked to modify a rocket balloon (i.e. one with a loud sound when the air released from the balloon) into a soundless normal balloon through an inquiry activity. Normally, majority of the students tried to roll up the mouth of the rocket balloon (i.e. increase the thickness of rubber). There was only one student showing a different method. The student tried to apply a circle of tape on the mouth of the rocket balloon (as shown in Figure 3). Wang shared this novel idea in class, instantly.

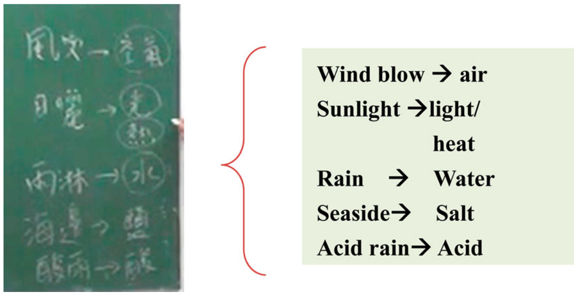


Figure 2. Identifying the key variables from each phenomenon.

Teaching practices that are supportive to students' convergent thinking

In this case study, Wang's teaching practices of convergent thinking can be classified into two major strategies: encouraging evidence-based conclusion and reviewing and commenting on group presentations. These strategies are discussed in the following sections:

Encouraging evidence-based conclusion

Interpreting data and evidence scientifically is one of the three competencies of scientific literacy on PISA 2015 draft science framework (OECD, 2013). Students were encouraged to be capable of drawing an appropriate scientific conclusion. In this case, while students proposed a way of collecting data and tried to draw an appropriate conclusion, Wang asked students to figure out whether their experimental data were appropriate to draw a compelling conclusion or not; for instance, as students designed an experiment to test whether a bee tried to inform its hive mates about the direction they must fly to reach the food (i.e. honey-rich pollen) through a special bee dance (as Figure 4).

After Wang reviewed the students' experimental design (as Figure 4), he asked them:

> According to your experimental design, as a bee back to its hive and informed its hive mates the direction of food sources through a special bee dance, you will record that if bees have or have not been attracted to the direction of food sources. In this case, do you think that we can make a different conclusion if 10 bees instead of 50 bees have been attracted to the destination? Which data would let you make a more compelling conclusion? and Why?

After students interacted with Wang, students realised that the number of bees that had been attracted to the direction of food source was an important variable and it should be added in their experimental design to draw a compelling conclusion.

For another activity, a group of students (i.e. group 4) decided to investigate the effect of the amount of candles on the time of burning when they are covered by a vessel (i.e. with limited amount of air). Students shared their experiment plan (i.e. research question, research hypothesis, experiment plan, and experiment result; as shown in Figure 5).

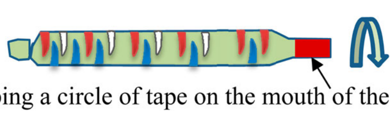


Figure 3. A novel idea to stop the whizzing sound of a rocket balloon.

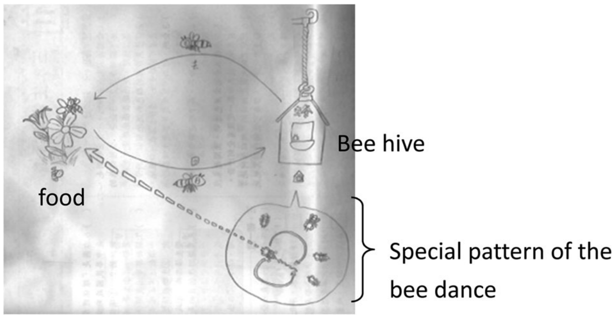


Figure 4. Students sketched out a way to test whether a bee informed his partners about the places of food (i.e. honey-rich pollen) through a special bee dancing or not.

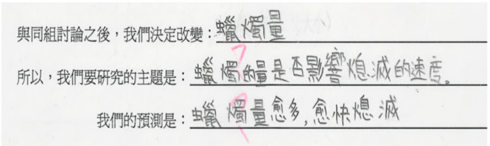
After students elaborated their experimental design and findings, a student critiqued that '*the amount of candles in the vessel A and vessel B were not the same … it would cause the differences of air volume (available for each candle) between vessel A and vessel B …*' The criticism inspired the whole class to review their design and conclusion. Wang then asked the students to figure out whether their data were sufficient to make the following conclusion: '*… amount of candles increase, time of burnout become shorter*'. In addition, students were reminded to consider the shortages of their previous experiment design. After students interacted with Wang, most students were aware that the volume of air in both vessels should be controlled with an equal amount of air. A method for avoiding unequal volume of air in both vessels was a critical shortage of their experimental design. Finally, the students realised that they have no sufficient empirical data to support the conclusion regarding how the amount of candles affected the time of burnout while the candles were put in different sizes of containers.

Reviewing and commenting on group presentation

'Critical thinking is required, whether in developing and refining an idea (an explanation or a design) or in conducting an investigation' (National Research Council, 2012, p. 46). Engaging students in refining and elaborating an argument is believed to be a useful strategy to promote their convergent thinking. While one group presented their experimental procedure and result in front of the class, other groups served as reviewers who were encouraged to review and comment on the group's presentation. In addition, after students compared the overall six groups' experimental results, they were asked to integrate and summarise the key factors of the experiment. For instance, after Wang shared former senior students' experimental data (as Figure 1), he encouraged students to practise on drawing a compelling conclusion as well.

T: Referring to your senior classmates' experimental data, can you make a conclusion that stirring speed or sugar's sizes affects the rate of sugar's dissolution. [*Wang presented senior's experiment designed*]
Class: No …
T: How do you modify the experimental design if you want to make the above mentioned conclusion?
S27: eh … step by step.
S3: low stirring speed, small sugar's size …

Research qustion and hypothesis:

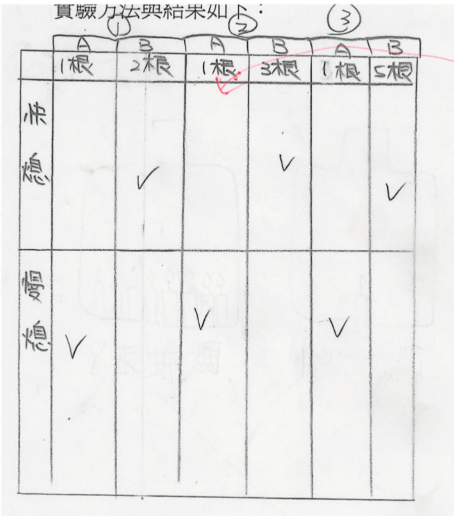


After group discussion, we decided to study the variable of amount of candles.

Research question: Were candles' burnout times affected by the amount of candles

Hypothesis: the more candles in a vessel, the faster the candles burnout.

Data:



Student obtained the following data:

Experiments	1		2		3	
Vessel	A	B	A	B	A	B
Amount of candles	1	2	1	3	1	5
Faster Burnout		V		V		V
Slower Burnout	V		V		V	

Experiment design: (e.g., third experiment desighn; one candle vs. five candles)

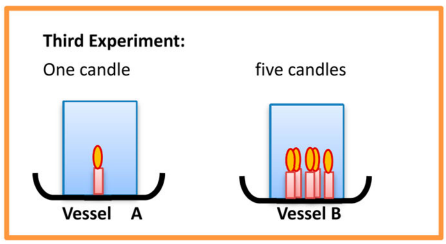


Figure 5. Candle burning experiment (three experiments were conducted to investigate candles' burnout times among cases of one candle vs. two candles, one candle vs. three candles, and one candle vs. five candles, respectively).

T: If you used an unequal stirring speed or unequal sugar's size at the same time, you can't identify which variable affect the rate of sugar's dissolution. Right?

…

T: S22, is your turn …

S 22: So … control the stirring speed, and then … use an equal amount of sugar, and then test it …

According to the aforementioned excerpts, students were encouraged to review and comment on group presentations. Critical thinking was practised while students tried to

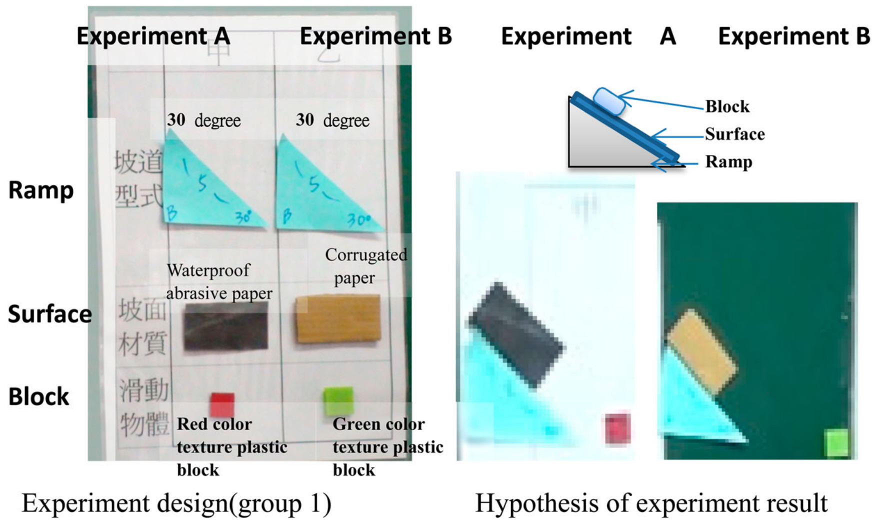


Figure 6. An experiment was performed to explore the relationship among types of surfaces and speed of a moving object.

evaluate and integrate peer-group designs and results and identify the related independent variables.

Another group presentation also showed the aforementioned assertion. In the topic of ‘force and friction’, students were encouraged to plan an approach to test: ‘Do different types of surfaces influence the moving speed of a same box?’ A package of picture cards was given to each group to test for three different angles of inclinations of ramps (i.e. 30 degree, 45 degree, and 60 degree) for two different types of ramp surfaces (i.e. corrugated paper and waterproof abrasive paper) by the sliding of two different types of test objects (i.e. red colour texture plastic block and green colour plastic block). A group of students (i.e. group one) shared their experiment design (as shown in Figure 6) in class. Other students were encouraged to review and comment on the experiment design.

After group one students presented their experimental design (as shown in Figure 6), Wang asked the students

> According to group 1 experiment design, as the red block slide down from the ramp more far away than the green block, you will make a conclusion that ‘waterproof abrasive paper’ has a higher friction than ‘corrugated paper’ …
>
> In this case, do you think that group 1’s experimental design is fair to make the aforementioned conclusion? Why not? … And how do you explain the unequal weight of the two blocks (i.e. confounding variable; green block vs. red block), it is possible that the box’s weight will affect the block’s moving speed?

After students reviewed and critiqued group 1’s presentation and their interaction with Wang, students realised that a defective experimental design (i.e. with confounding variables) will draw out an inconclusive conclusion.

Discussion

The study presented in this article provides two noteworthy findings that give insights into effective strategies for developing creative science thinking. The first noteworthy finding from this study is that the experimental group students made significant progress and outperformed their counterparts on the performances of science inquiry and convergent thinking. Although additional studies are needed to confirm practical utility, the initial findings provide empirical evidence to confirm the effectiveness and feasibility of promoting students' creative science thinking through well-planned classroom teaching. As empirical studies on exploring the development of students' scientific creativity are scarce (Kind & Kind, 2007), especially for beginning science learners, the fruitful learning outcome of this study can be used to encourage science teachers and researchers who are interested in scientific creativity to try similar theory-based learning materials or instructional strategies as those used in this study.

The second noteworthy finding from this study is that effective strategies for developing divergent and convergent thinking have been identified, respectively, through qualitative data of classroom observations along with interviews. In addition, the effects have been supported by quantitative data analysis of student progress on the two cognitive thinking performances. Based on our understanding, to date there is no empirical study in the International Journal of Science Education focused on the investigation of teaching strategies for promoting creative science thinking. The identification of effective teaching strategies provides insights into the literature of this field. Previous literature indicates that new models and hypotheses are most often generated through interactions and discussions among knowledgeable scientists. For example, the National Research Council (2013) stated that

> new ideas can be the product of one mind or many working together. However, the theories, models, instruments, and methods for collecting and displaying data, as well as the norms for building arguments from evidence, are developed collectively in a vast network of scientists working together over extended periods. (p. 27)

The National Research Council continues to state that 'scientists need to be able to examine, review, and evaluate their own knowledge and ideas and critique those of others' (p. 27). Although the participants in this study are not knowledgeable scientists, their active interactions in small groups and in whole class discussions, along with the effective teaching strategies of facilitating associative thinking, sharing impressive ideas, encouraging evidence-based conclusions, and reviewing and commenting on group presentations, enable them to make progress on divergent and convergent thinking. It is encouraging to see the beginning science learners engaging in active collaboration for identifying and controlling variables, planning investigation procedures, collecting and analysing data, and presenting and communicating results like typical scientists do in laboratories. It is hoped that the identification of effective teaching strategies opens a window to allow future studies to develop and confirm ways of promoting students' creative science thinking.

It should be noted that effective teaching strategies in promoting creative science thinking are many and varied. The strategies reported in this study might be limited in the specific context and culture. Additional cross-site and cross-culture comparison would greatly add to the collective understanding of teaching scientific creativity. Despite our attempt to minimise the experimental group students' perception of being given special treatment, another limitation of the study is the possibility of the Hawthorne effect (Adair, 1984) (i.e. part of the experimental group students' progress might have resulted from their awareness of being observed). Nevertheless, as mentioned earlier that little is known about effective ways of promoting students' creative science thinking (Kind & Kind, 2007), this study sheds additional light on the current literature by identifying effective teaching strategies for engaging students in divergent and convergent thinking. The initial fruitful result of student progress in the study should be used to leverage the importance of encouraging students' creative science thinking and to set the priority of promoting teachers' professional development in science instruction.

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