科技部補助專題研究計畫成果報告
期末報告

以探究論證科學營提升國小女學童情意學習及論證能力之探討（第3年）

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中文摘要：本研究目的主要探討高雄市國小四年級學童參加論證導向探究課程，對於提升學童科學參與及論證能力之成效。本研究選取高雄市某國小36位學生作為實驗組並實施論證導向探究課程，另外選取該校同年級36位學生作為對照組，填寫前後測問卷。除此外，從實驗組中挑選科學參與或論證能力前測獲得最高分的4位學童及最低分的4位學童為目標學生，進行課室觀察及個別訪談。本研究以科學參與量表與論證能力測驗為研究工具，經由探索性因素分析考驗其信效度，並以共變數分析比較實驗組與對照組學生之差異性。研究結果發現，經由論證導向探究課程之後，實驗組學生的科學參與和論證能力總分，以及論證能力中的「主張」和「論述」兩個分向度均顯著高於對照組，而「科學學習焦慮」向度分數則顯著低於對照組；且科學參與和論證能力的後測總分有顯著正相關。此外，訪談與觀察結果亦獲得與量化資料一致的發現。研究結果可作為改進自然與生活科技學習領域及相關課程與教學研究之參考依據。

中文關鍵詞：論證能力、國小學童、科學參與、論證導向探究課程

英文摘要：This study explored the effects of a modified argument-driven inquiry approach on Grade 4 students' engagement in learning science and argumentation in Taiwan. The students were recruited as an experimental group (EG, n = 36) to join a 12-week study, while another 36 Grade 4 students from the same schools were randomly selected to be the comparison group (CG). All participants completed a questionnaire at the beginning and end of this study. In addition, four target students with the highest and the other four students with the lowest pretest engagement in learning science or argumentation to be observed weekly and interviewed following the posttest. Initial results revealed that the EG students' total engagement in learning science and argumentation and the claim and warrant components were significantly higher than the CG students. In addition, the EG students' anxiety in learning science significantly decreased during the study; and their posttest total engagement in learning science scores were positively associated with their argumentation scores. Interview and observation results were consistent with the quantitative findings. Instructional implications and research recommendations are discussed.

英文關鍵詞：Argumentation; elementary students; engagement in learning science; modified argument-driven inquiry; Taiwan

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ABSTRACT
This study explored the effects of a modified argument-driven inquiry approach on Grade 4 students' engagement in learning science and argumentation in Taiwan. The students were recruited as an experimental group (EG, $n = 36$) to join a 12-week study, while another 36 Grade 4 students from the same schools were randomly selected to be the comparison group (CG). All participants completed a questionnaire at the beginning and end of this study. In addition, four target students with the highest and the other four students with the lowest pretest engagement in learning science or argumentation to be observed weekly and interviewed following the posttest. Initial results revealed that the EG students' total engagement in learning science and argumentation and the claim and warrant components were significantly higher than the CG students. In addition, the EG students' anxiety in learning science significantly decreased during the study; and their posttest total engagement in learning science scores were positively associated with their argumentation scores. Interview and observation results were consistent with the quantitative findings. Instructional implications and research recommendations are discussed.

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The Organisation for Economic Co-operation and Development [OECD] (2010) has reported that engagement in learning science is regarded as an essential outcome of science education, and contributes to students' choices in future science career. However, there are several international research studies documenting a decline over time of student's active engagement in formal science learning and in their further study of science subjects (e.g. Osborne & Dillon, 2008; Tytler, Symington, & Smith, 2011). Hulleman and Harackiewicz (2009) revealed that the essential driver of engagement in learning science is interest towards a science activity or curriculum, which could provide us a clear process to understand learner's engagement in learning science stage by stage. Ainley, Hidi, and Berndorff (2002) further clarified the 'interest' can be referred to as a psychological state or a selective preference towards particular domain of the study. Hidi (1990) has distinguished two types of interest: 'situational interest' and 'individual

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interest'. The situational interest is a short-term preference which can be generated by particular conditions such as a demonstration of a discrepant event or a novel hands-on experiment. Hampden-Thompson and Bennett (2013) found that greater levels of student motivation, enjoyment, and future orientation toward science were associated with various measures of engagement in learning science.

During the past two decades, argumentation has been recognized as an essential ability in the development of democratic societies in order to assist individuals to judge multiple opinions and make appropriate decisions (e.g. Driver, Newton, & Osborne, 2000; OECD, 2006; Osborne, Erduran, & Simon, 2004). The National Research Council (NRC, 2012) indicates that argumentation is considered an important scientific and engineering practice and goal of science education; its *Next Generation Science Standards* (NRC, 2013) suggest that students should be engaged in argumentation based on evidence, provide rational explanations, and evaluate and justify information from multiple sources during meaningful inquiry. However, in spite of argumentation being emphasized and considered as a central ability of students, whereas high-stakes examinations are still one of the important ways to assess students' science performance regardless of school or national level in Taiwan (Lee, Johanson, & Tsai, 2008), it appears that Taiwanese teachers are slow to implement recommended instructional innovations because they are not convinced that these approaches have the potential to promote science knowledge as well as other important outcomes. Lee, Tsai, and Chai (2012) found that science teaching in Taiwan has traditionally been focused on science content—the bedrock of the curriculum and school science examinations. In addition, Chang, Hsieh, and Shyu (2010) analyzed the Programme for International Student Assessment (PISA) 2006 data and found that Taiwanese students performed poorly in using evidence to make a conclusion and find the useful information from related data or reports; a similar finding was found in the PISA 2012 data (OECD, 2014).

Hong, Lin, Wang, Chen, and Yang (2013) found Taiwanese student's argumentation ability while participating in and discussing relevant public issue could help them to analyze different evidence effectively and avoid blindly following unquestioned claims and making uniformed decision. Therefore, students—who will become future citizens, leaders, and decision-makers—need to develop their argumentation ability so as to avoid making detrimental decision toward society, which is the central goal of mainstream science literacy, therefore this study explored the effectiveness of an argument and inquiry approach to improve elementary school students' argumentation ability and engagement in science. The research questions (RQ) are:

(1) How effective is the modified argument-driven inquiry on enhancing elementary school students' engagement in learning science and argumentation?
(2) What are the differences between the EG and CG students' engagement in learning science and argumentation with different achievement levels?
(3) What relationships exist within the EG students' engagement in learning science and argumentation?

Background

Despite their apparent complementarities, commonalities, and dynamics, the relationship between students' engagement and argumentation in science has not been empirically demonstrated. The uniqueness of this study is the synchronized measurements of engagement in learning science and argumentation to gather rich data using a student questionnaire and embedded paper–pencil learning sheets, classroom observations, and follow-up interviews with target students, their parents, and science teachers. These information sources allowed triangulation of quantitative and qualitative information to construct and support assertions about the effects and relationships amongst the instruction, argumentation, and engagement in science.

Definitions of engagement in learning science

Fredricks, Blumenfeld, and Paris (2004) defined that

> engagement was comprised of three interconnected aspects: *behavioral engagement* which includes students actively participating in learning activities, *emotional engagement* which includes having positive feelings about learning activities, and *cognitive engagement* which includes the willingness to exert the effort necessary to comprehend complex ideas and master difficult skills. (p. 60)

All types of engagement are likely related to school activities. The definitions of engagement not only provide a multifaceted explanation of engagement, but also suggest researchers to explore and interpret the degree of engagement from different aspects. A review of the literature reveals that the exploration of engagement in learning science tended to focus on more complex, multidimensional constructs (OECD, 2006; Woods-McConney, Oliver, McConney, Maor, & Schibeci, 2013). For instance, the OECD (2006) views engagement in science as a multidimensional suite of affective variables including students' interest, enjoyment, valuing, self-efficacy, self-concept, and motivation in science. In addition, the PISA index of engagement of science was derived from the students' level of agreement with statements of 'I generally have fun when I am learning science topic' and 'I am happy doing science problems'. In view of the above literature, this study concentrates on exploring students' emotional and cognitive engagement, and combines some important affective variables that derived from OECD (2006).

The emotional engagement encompasses affective responses to science that include constructs of attitude toward, enjoyment, anxiety, pleasure, interest in science (Ainley & Ainley, 2011; Woods-McConney et al., 2013); the cognitive engagement concerns on students' willing to work and measure their science concepts and skills, such as motivation and self-regulation of learning (Fredricks et al., 2004; OECD, 2006). Some studies have found that students' engagement and their science performance are related, for instance, Kahraman (2014) analyzed TIMSS 2011 data on the 7479 4th graders and 6928 8th graders from Turkey and found that in parallel with the decrease in students' emotional engagement, their participation in the academic activities and behavioral engagement also showed a tendency to decline. In addition, Miller et al. (2014) study with 130 elementary school students and they found that an increased engagement led to increased conceptual growth.

Studies related to students' engagement in learning science

While the benefits of *science literacy for all* are widely heralded, the general decline of school and post-school engagement in science has also been acknowledged internationally

(Marginson, Tytler, Freeman, & Roberts, 2013; Sjaastad, 2012). A study of PISA data for New Zealand and Australia revealed that students' engagement in science is most strongly associated with science-related that students do outside of school (Woods-McConney et al., 2013). Furthermore, path analyses revealed that four factors had positive direct effects on Taiwanese 15-year-old students' future intended interest: current interest, followed by enjoyment, self-efficacy, and engagement (Lin, Hong, & Lawrenz, 2012). This means that students who were interested in science subjects and reported higher self-efficacy or current engagement in leisure science activities were more likely to report they would be interested in learning science-related issues in the future.

Several researchers have addressed ideas and approaches aimed at improving students' positive attitudes in order to increase their engagement in science (Chen, Wang, Lin, Lawrenz, & Hong, 2014; Gilbert, Bulte, & Pilot, 2011; Jenkins, 2011; NRC, 2007). Chen et al. (2014) and Jenkins (2011) asserted that teachers need to conduct context-based science education that is relevant and coherent with students' daily lives and that provides students tangible reasons for engaging in and continuing with lifelong science learning. In addition, NRC (2007) claimed that, for primary school children, science teaching needs to focus on *big* ideas with broad explanatory power that will help them understand the distinctive value of science and prepare them for further learning in science.

How students' engagement and argumentation can be improved?

Simon and Johnson (2008) suggested that students, as future citizens, should be able to engage in decision-making about controversial issues in science and to understand, explain, and evaluate the evidence provided in science about the target issues. Venville and Dawson (2010) suggested that literate citizens should be able to voice their well-justified or evidence-based conclusions and demonstrate logical, rational patterns of reasoning to support their arguments. However, putting this suggestion into action involves how to educate students about why we believe in a scientific view, to see science as a distinctive and valuable way of constructing knowledge, and to focus science teaching more on the evidence and arguments about scientific ideas. If science teaching achieves these pedagogical goals, it will help students develop fruitful argumentation abilities and deeper understandings.

Research on children's learning has provided compelling evidence that they are capable of reasoning (NRC, 2007). Reznitskaya, Anderson, and Kuo (2007) found that Grades 4 and 5 students can grasp and verbalize important properties of an argument. Furthermore, there has been an increase in argument-based approaches exploring how to better support K–12 students (Hong et al., 2013; McNeill, 2011; Simon, Erduran, & Osborne, 2006). These approaches have focused on a variety of different strategies such as the use of curriculum materials, teaching strategies, and student interaction. McNeill (2011) explored New England Grade 5 students' views of explanation, argument, and evidence across three contexts: what scientists do, what happens in the science classroom, and what happens in everyday life; she found that students' understandings of explanation and argument increased over the course of the school year.

Teaching argumentation through the use of appropriate activities and teaching strategies can provide a means of promoting social, reasoning, and evidence-based argument goals (Osborne et al., 2004; Simon et al., 2006). This change in emphasis will require science teachers to adopt more dialogic approaches (Alexander, 2005; Mortimer & Scott, 2003) that can involve students in discussion activities and consider how they interact with peers to foster argumentation skills. However, practical work has been found to produce no long-term gains in generating engagement in science (Abrahams, 2009). Some of this lack of long-term engagement may be the result of the nature of practical work in schools. Students might be able to recall the experiments and what happened, but they may not be able to explain why they got their results and what scientific ideas were behind the exercise since practical exercises may not be linked effectively (Hampden-Thompson & Bennett, 2013). Abrahams and Millar (2008) suggested that much practical work seems to be preoccupied with students being able to produce the intended outcome. It is not surprising that participation in hands-on experiments was not associated with interest in school science, especially for girls (Jocz, Zhai, & Tan, 2014); they suggested that the design of activities should focus on novelty, opportunities for discussion, and connections to real life.

Significance of this study

Although many previous studies have focused on the importance of argumentation and instruction about argument skills for high school or college students (e.g. Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013; Sampson & Walker, 2012), limited attention has been paid to the investigation of elementary school students' argumentation abilities and appropriate instructional practices. In addition, in light of a four-phase model of interest development proposed by Hidi and Renninger (2006), students may be able to trigger and maintain situational interest through engaging in novel and interesting inquiry-based science activities; then emerge individual interest cumulatively by the continuous and long-term program; gradually become well-developed individual interest to engage in learning science and consequently decrease their anxiety in learning. Therefore, we hypothesized that if elementary school students were engaged in a modified argument-driven inquiry (ADI; Sampson & Walker, 2012) approach, then they might enhance and maintain their situational interest, transfer it into individual interests (Lin, Hong, & Chen, 2013; Logan & Skamp, 2013), and improve their argumentation and engagement in learning science. Most importantly, positive findings of enhancing student engagement and interest in learning science of this study can be served to mitigate not only elementary but also secondary science teachers' concerns and anxieties about innovative curriculum and novel teaching strategies.

Methods

A quasi-experimental design (Cohen, Manion, & Morrison, 2007) with non-randomly assigned experimental and comparison groups was employed in this study. Pretests and posttests documented initial performances and gains for the two groups over the duration of the study, while observations and interviews supplemented the quantitative data.

Participants and settings

A total of 72 Grade 4 students from two typical and similar elementary schools in southern Taiwan-Kaohsiung city participated in this study. The schools were selected because they were comprehensive and had diverse populations. The experimental group (EG) consisted of 36 volunteers (14 boys and 22 girls) and the comparison group (CG) consisted of 36 randomly selected volunteers (20 boys and 16 girls) from the same schools. In addition, four target students with the highest and the other four students with the lowest pretest engagement in learning science or argumentation from the EG were recruited to be observed weekly and interviewed following the posttest.

Data collection

The EG and CG students completed pretests and posttests in the beginning and at the end of this study. The eight target students were observed weekly; these children and their parents and science teachers were interviewed at the end of the treatment.

Treatment and procedure

The EG students participated in a 12-week program (24 hours) of Modified ADI on Friday afternoons in a typical elementary school science laboratory while the CG students were in their regular science lessons in their normal classrooms. The eight target students were observed weekly during the study and interviewed individually upon the completion of the study. The ADI teaching approach has been documented for secondary school and college students to enhance engagement, writing, speaking, and reading scientific argumentation and their ability to evaluate peer argument (Sampson, Enderle, Grooms, & Witte, 2013). We modified and retained identification of the task, the generation of data, production of a tentative argument, and argumentation session to match up to the learning level of children. Obviously, in the current study, each small group students have to finish the worksheet of the inquiry process and simple investigation report, and present to other small groups and accept critique publicly instead of exact double-blind peer review and revise.

The ~100-minute modified ADI provided the following focused learning opportunities and time allotments: (a) identifying a focus task from a demonstration or presentation (15 minute), (b) identifying related research questions (10 minute), (c) making hypotheses related to the research questions (5 minute), (d) designing an investigation and procedures (10 minute), (e) collecting data from hands-on activities (30 minute), (f) providing evidence-based conclusion (15 minute), and (g) forming and sharing the group argument and critiquing and refining its explanations and evaluation (15 minute). The study covered six curriculum topics (i.e. sound, magnetic force, capillarity, light, gravity, and static electricity) involving 12 ADI activities over the 12 weeks.

A sample modified ADI activity called an 'Egg Protecting Mission'. Each team was assigned a challenging mission that required them to make a special design to protect their egg from any damage when the egg was dropped from the fourth floor of the school building to the ground. After completing the hands-on activity, each group member discussed and wrote down their findings, claims, and explanations related to the activity. Each team was encouraged to explain and write down possible reasons of how their design related to scientific principles; a whole class discussion was implemented to clarify each team's claims, findings, warrants, and providing rebuttal to other teams. Finally, the teachers discussed the established knowledge and possible conclusions and variations in students' findings.

The CG students continued with their normal science lessons and regular classroom teachers. The lessons were teacher-directed considerations of the textbook supplemented with teacher presentations, completion of study guides, and occasional demonstration or cookbook experiments. These lessons followed the prescribed curriculum topics (i.e. magnetic toys, gravity force, capillarity of water, magical light, and substance of conducting electricity) and did not cover the same ideas as covered in the EG inquiries. Therefore, conceptual understanding and knowledge were not considered as central outcomes for comparing the EG and CG students.

Development and validation of instrument

This study required the development of a measure for science learning engagement and argumentation abilities. This measure was based on established procedures.

Student questionnaire (SQ)

The 51-item, investigator-developed SQ included three sections: demographic information, engagement of learning science scale (ELSS), and argumentation test. The first section elicited the respondent's personal information (i.e. gender, age, grade level, overall academic performance, and academic performance in science).

The second section contained the 45-item Chinese version of ELSS derived from 51 items found in the attitude toward science measures scale (Kind, Jones, & Barmby, 2007) with six subscales (i.e. learning science in school, self-concept in science, practical work in school, science outside school, future participation in science, importance of science). Preparing the ELSS involved translating the instrument to Chinese and back-translating to English to validate the translated version (Brislin, 1986). Any discrepancies were discussed and resolved through translation by another science educator. This iterative process was repeated until no error in translation was found (Chen et al., 2014). Participants were asked to rate each ELSS item using a 5-point Likert scale (5 = strongly agree … 1 = strongly disagree). A panel of science educators examined these items to explore construct validity.

Validation of the ELSS used exploratory factor analyses (EFA) with Varimax rotation of responses received from a pilot study of elementary school students ($n = 119$) to confirm that the factor structure aligned with the intended design structure. We examined a Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity (Tabachnick & Fidell, 2001) that revealed a moderate–high KMO of 0.81 and a significant difference of all items, approximately $\chi^2_{(1035)} = 3{,}539.766$, $p < .001$. These results justified an EFA that revealed six components (45 items retained and 6 items omitted from further consideration) aligning with the original design, which accounted for 57% of the variance.

The first factor, learning motivation toward science, included 11 items with a total score range of 11–55 and accounted for 13% of the variance; a sample item is *I would like to be a scientist*. The second factor, enjoyment in learning science, included eight items with a total score range of 8–40 and accounted for 12% of the variance; a sample item is *I look forward to doing science practical experiments at school*. The third factor, positive affection toward school, included eight items with a total score range of 8–40 and accounted for 9% of the variance; a sample item is *I get on well with most of my teachers*. The fourth factor, anxiety in learning science, included seven items with a total score range of 7–35; all items are reversed coding; therefore, a high score indicates less anxiety in learning science; it accounted for 8% of the variance; a sample item is *The science is difficult for me*. The fifth factor, self-confidence in learning science, included five items with a total score range of 5–25 and accounted for 8% of the variance; a sample item is *Science is my best subject*. The sixth factor, pleasure in learning science included six items with a total score range of 6–30 and accounted for 7% of the variance; a sample item is *Learning science is pleasure for me*.

The 45-item ELSS had a high internal consistency (Cronbach's $\alpha = .92$); the internal consistency coefficients for the six factors were .90, .89, .81, .84, .81, and .86, respectively (Table 1 provides descriptive statistics on all items). These results based on an established measure indicated that the ELSS has appropriate validity and reliability.

The third section included two argumentation ability tests. One item was derived from Hong and Lin (2011); the other item developed for use in this study was: *One long candle and another short candle were put in a beaker and lit, as in the figure. If the beaker was covered by a piece of glass, which one of the two candles would be extinguished first (the longer one or the shorter one)? Please explain the reason in your own words and provide as much evidence or as many theories as possible to support your prediction. If someone else has a different prediction from yours, how are you going to persuade the person that your prediction is correct?*

Argumentation in Taiwan has received increasing research attention, but there is no requirement to teach argumentation in the elementary schools. Therefore, this study sought to identify and use established approaches that might be embraced and implemented by elementary teachers. We identified the argumentation pattern (TAP; Toulmin, 1958) and analytical framework (Osborne et al., 2004) as resources for development of instructional scaffolding and for scoring students' argumentation performance (Lin et al., 2012). TAP has been widely used as the basis evaluation of students' argumentation (Grace, 2009; Hong et al., 2013, Lin et al., 2012; Osborne et al., 2004). The main components of TAP are claims (conclusions, propositions, assertions), data (evidence used to support the claim), warrants (statement of the relationship between the data and the claim), and rebuttals (statements or counterarguments to refute the claim).

With the consideration that elementary school students are beginning science learners and still at the age of developing writing ability, their arguments may not be well qualified for high-level categories with significant or multiple rebuttals. We referenced the five-level scoring scheme of Osborne et al. (2004) and designed a four-level coding structure (i.e. 0∼3) to assess students' quality of argumentation, claims, evidence, warrants, and rebuttals in this study (Table 2). A coding score of 0 represents an irrelevant applicable/no answer provided; 1 indicates a low level with simple or unclear components; 2 shows a moderate level with clear and partial components; and 3 represents a high level with clear and complete components of argumentation quality. Therefore, a higher score for the components indicates better argumentation, and the sum of the component scores provides an indication of overall argumentation ability.

Individual interviews protocols

Semi-structured interview protocols were developed to further investigate the effects of the modified ADI on eight target students, their parents, and their science teachers. These

Table 1. Means, standard deviations, factor loadings, and reliability characteristics of engagement in learning science scale (ELSS) items ($N = 119$).

Dimensions/Items	*M*	SD	Factor loading	Correlation with total score	Alpha if item deleted
Learning motivation toward science (11 items)					
1. I would like to be a scientist.	2.96	1.48	.82	.56	.92
2. I would like to be a science teacher.	2.80	1.41	.75	.45	.92
3. I would like to engage in scientific projects.	3.39	1.35	.71	.64	.92
4. I would like to select major in science at college.	3.35	1.36	.70	.67	.92
5. Be a scientist is an attractive job for me.	3.41	1.32	.61	.70	.92
6. I like reading scientific articles, magazines and books.	3.17	1.23	.58	.49	.92
7. Understanding more scientific knowledge is my favorite.	3.82	1.17	.54	.69	.92
8. I would like to have a job with science or technology.	3.05	1.35	.54	.59	.92
9. I like to visit science museums.	3.72	1.34	.49	.57	.92
10. I like watching scientific programs through medias.	3.20	1.33	.49	.56	.92
11. I attend scientific activities in school and after school very often.	4.13	1.29	.46	.50	.92
Enjoyment in learning science (8 items)					
12. I look forward to doing science practical experiments at school.	4.16	1.15	.82	.51	.92
13. I enjoy doing hands-on activities at science class.	4.08	1.20	.78	.57	.92
14. We understand more scientific knowledge through science practical experiments.	4.03	1.18	.74	.55	.92
15. I enjoy obtaining more scientific knowledge from hands-on activities.	4.09	1.21	.74	.38	.92
16. I enjoy involving practical experiments at science class.	3.84	1.32	.68	.36	.92
17. Science class is full of exciting things for me.	4.15	1.27	.67	.40	.92
18. I enjoy working together with my team members at science class.	4.16	1.26	.67	.46	.92
19. It is exciting for me to learn new things about science.	3.76	1.21	.47	.63	.92
Positive affection toward school (8 items)					
20. I get on well with most of my teachers.	3.68	1.24	.73	.28	.92
21. I work as hard as I can in school.	3.41	1.36	.73	.52	.92
22. I am happy when I am in school.	3.85	1.31	.73	.40	.92
23. I feel that I belong in my school.	3.89	1.34	.63	.37	.92
24. I would recommend this school to others.	3.56	1.41	.59	.41	.92
25. I really like my school.	3.61	1.43	.56	.47	.92
26. My science class is full of fun.	3.69	1.25	.45	.48	.92
27. I find my school is boring.[a]	3.57	1.32	.39	.37	.92
Anxiety in learning science (7 items)					
28. The science is difficult for me.[a]	2.89	1.44	.81	.15	.92
29. The science class is boring for me.[a]	3.13	1.57	.78	.12	.92
30. I feel helpless when doing science.[a]	3.06	1.26	.76	.11	.92
31. Practical work in Science is boring.[a]	3.39	1.57	.68	.03	.92
32. I am not good at Science.[a]	3.00	1.41	.67	.18	.92
33. I feel nervous in science class.[a]	3.18	1.62	.65	.02	.92
34. Most of the time I wish I don't need to attend science class.[a]	3.13	1.56	.59	.09	.92
Self-confidence in learning science (5 items)					
35. Science is my best subject.	3.07	1.34	.64	.61	.92
36. I understand everything in Science class.	3.17	1.23	.63	.55	.92
37. I get good marks in Science.	3.10	1.25	.62	.45	.92
38. Science and technology makes our lives easier and more comfortable.	3.66	1.25	.54	.54	.92
39. I learn Science quickly.	3.13	1.29	.51	.52	.92
Pleasure in learning science (6 items)					
40. Learning Science is pleasure for me.	3.84	1.24	.76	.60	.92
41. I spent most of time in learning science.	3.87	1.20	.66	.56	.92
42. I would like to have more science class in school.	3.87	1.13	.50	.63	.92

(*Continued*)

Table 1. Continued.

Dimensions/Items	*M*	SD	Factor loading	Correlation with total score	Alpha if item deleted
43. The time passes fast in the Science class.	3.45	1.32	.49	.57	.92
44. There are many exciting things happening in science class.	4.05	1.14	.48	.65	.92
45. We learn many interesting things in science class.	4.00	1.14	.36	.58	.92

[a]Reversed items that have been reversed coded.

respondents were individually interviewed by the investigators for 20–30 minute using specific protocols. A sample student interview question was: *Please give me some examples to describe any changes of your engagement in learning science and argumentation while joining the approach*? A sample interview question for parents and science teachers was: *Please give me some examples to describe any differences of your child's/students' engagement in learning science and argumentation during the study*? All interviews were audiotaped and transcribed into searchable text files.

Student observation form

Contextual information about engagement and argumentation ability were collected on the target students using *in situ* observations. The investigators developed a six-category observation form to record students' behaviors suggestive of engagement and argumentation. We developed a two-category scoring rubric that was based on the classroom observation coding schedule (Pellegrini, 1996), considered as valid and reliable methods for experimental or field settings to quantify students' behaviors. Weekly observations were made by two experienced science education graduate students and researchers, who were assigned specific students to observe over the 12-week study. The time-sensitive observations allowed comparisons of student performance over the study's duration so as to detect students' changes on engagement in learning science and quality of argumentation.

Data analyses

First, we performed independent *t*-tests on the pretest data for the EG and CG to determine if the sampling procedures established similar groups on engagement in science learning and argumentation. Second, analyses of covariance (ANCOVAs) were conducted to examine the main effects of treatment on the ELSS and argumentation between EG and CG. Third, Kruskal–Wallis one-way analyses of variance (ANOVAs) by ranks tests were conducted to investigate EG students' differences among different achievement levels in terms of ELSS and argumentation after participating in the ADI approach. Fourth, correlation analysis was used to explore the association between engage and argumentation. Finally, content theme analysis (Patton, 2002) was used to analyze the weekly observation and individual interview results. In the current study, at first, we read and annotated transcripts repeatedly to familiarize ourselves with data. Then, we identified the key themes or topics which were repeated across the data, including learning motivation toward science, enjoyment in learning science, positive affection toward school, anxiety in learning science, self-confidence in learning science, pleasure in learning science, and claims, data, warrants, and rebuttals of argumentation. Moreover, we developed a coding

Table 2. Description, coding, and examples of the argument levels.

Description	Level	Coding	Example of student argument
Making a claim	Irrelevant/not applicable/ not provided	0	I don't know. I am not sure.
	Low level: simple or unclear claim	1	I think that the water is full of special liquid. [*cite: Transformation of Toothpicks activity*] I find the color of water is different from pure water.
	Moderate level: clear and provide partial claim	2	I consider certain kind of substance maybe make curved toothpick to be unfolded. The toothpick is not really broken, so it might relate to a physical principle.
	High level: clear and complete claim	3	I think it is water rather than oil or other liquids because I saw a similar experiment before. I think bent toothpicks might saturate with water and be unfolded.
Providing evidence (e.g. data or research findings) to support the claim	Irrelevant/not applicable/ not provided	0	I follow other team to do it! I have no idea!
	Low level: one relevant evidence	1	We found that if we wrap it up with more layers and as thick as possible, the egg will not hit the hard ground directly through the cushioning effect. [*cite: Egg protecting mission activity*]
	Moderate level: clear and provide partial evidence	2	I believe the key factor is falling speed. In order to keep eggs unbroken, we use plastic bag to make a parachute which ties egg box with string. Our record indicates that parachute could let egg box fall slowly.
	High level: more than two reliable and sufficient evidences	3	I remember that notebook mention the air full of air foam that could avoid physical strike from outside, so that it could keep eggs unbroken when we throw it from high altitude. Besides, we can also see some fruit or expensive equipment are wrapped with air foam during transportation delivery. I consider both collision power and landing speed. From the findings, I provide three evidences to support our claim: (1) the sponge layers can absorb physical impact toward eggs; (2) when I put eggs in a medium paper cup and wrap it up with tape tightly, it can keep eggs from vibration; (3) design combining eggs with a parachute, air resistance then the speed of descent can be slow down.
Explaining the relationship between evidence and claim	Irrelevant/not applicable/ not provided	0	The toothpicks change its shape suddenly [*cite: Transformation of Toothpicks activity*]. It is science magic!
	Low level: relevant warrant	1	What he adds is water because of the surface tension.
	Moderate level: partial warrant	2	I have the other reason to support my claim; I consider water will move along the slit of folded toothpicks, so it will expand the slit slowly.
	High level: explicit and rational warrant	3	I am really sure; the liquid should be water, because the principle of buoyancy cause to toothpicks expanded. When we added enough water, the water will produce buoyancy so that bent toothpicks float in water and expanded. I disagree with this argument. Although I also believe that what it added is water, it should be caused by capillarity actually. While bent toothpick fibers absorb water, it will become unfolded and straight to change back to original state. Therefore, it's right to add water.

(*Continued*)

Table 2. Continued.

Description	Level	Coding	Example of student argument
Making a rebuttal	Irrelevant/not applicable/ not provided	0	I agree with your argument. I have no idea!
	Low level: weak rebuttal	1	I don't think if you the eggs were wrapped many and many layers of sponges, eggs, they will be totally safe, I saw some eggs are broken.
	Moderate level: partial rebuttal	2	I don't think so! If we throw eggs heavily, it might break. On the other hand, when the eggs are wrapped cushion with thick liquid made from corn flour without any device used to fix eggs.
	High level: strong and identifiable rebuttal	3	Styrofoam material can't bend, and it usually presents in box-shaped. Hence, if we put eggs inside a Styrofoam container, there are still spaces between eggs and container itself to cause the problem of vibration. Then, sponge also serve the purpose of reduce physical impact, but we need to consider other factors, such as the power of throwing, higher altitude, acceleration of gravity, or there are sharp stones on the ground, otherwise eggs will still break.

scheme to identify and determine the pieces of data which corresponded to each theme. Finally, we searched for patterns and associations within the categorized data to interpret cases' engagement in learning and argumentation in detail. In addition, we report effect sizes for statistical significance results, allowing readers to interpret the results (Cohen, 1994; Kirk, 2001).

Results

The results are reported in an ordered fashion to establish similarity between the EG and CG at the outset of the study and then to address each of the three research questions. The independent *t*-tests of the pretest results revealed no significant ($p > .05$) differences on the total measures and any subscale. However, the slight pretest differences, Grade 3 science achievement differences, and the potential associations between prior academic performance and ELSS, $r = .25$, $p = .038$, and argumentation, $r = .38$, $p = .001$, justified use of the more conservative ANCOVA where possible to explore treatment effects.

> RQ1. How effective is the modified argument-driven inquiry on enhancing students' engagement in learning science and argumentation?

The ANCOVA with the pretest ELSS scores as the covariate was used to explore the treatment main effect on posttest ELSS scores (Table 3). The ANCOVA results indicated that the adjusted posttest ELSS scores of the EG students are significantly higher than the CG on the total ELSS, $F(1, 69) = 4.74$, $p = .033$, $\eta_p^2 = 0.06$, and on the anxiety in learning science subscale, $F(1, 69) = 4.19$, $p = .044$, $\eta_p^2 = 0.06$. The ANCOVA results for all other subscales did not reveal significant treatment effects.

The ANCOVA results for argumentation (Table 4) with the pretest scores as the covariate indicated that the adjusted posttest scores of the EG students are significantly higher than the CG on total argumentation score, $F(1, 69) = 10.29$, $p = .002$, $\eta_p^2 = 0.13$, and two components of argumentation: claim, $F(1, 69) = 17.81$, $p < .001$, $\eta_p^2 = 0.21$, and warrant,

$F(1, 69) = 5.27$, $p = .025$, $\eta_p^2 = 0.07$, than the CG counterparts. The ANCOVA results for all other argumentation components were not significant.

Observation results

The eight target students' behaviors were observed during the ADI approach; the behaviors were summarized over Weeks 1–6 and Weeks 7–12 to detect changes in their engagement in learning science and argumentation (Figure 1). Early-late performance comparisons indicate increases across all of these low- and high-performing target students. Three students (Yang, Lee, and Yin) provided interesting examples of changing engagement and argument.

Yang was a high engagement girl; she enjoyed all activities and participated with team members very often during the modified ADI activities. She made significant progress and changes over the early and late periods of the study. Her engagement in learning science dramatically improved from 43% to 66%. Lee was a low engagement boy; he was attracted by and involved in all ADI activities. Lee's engagement in learning science improved from 17% to 43% and his argumentation slightly increased from 0.2% to 2%. Hsian was a low argumentation girl on the pretest but her argument skill slightly increased from 0.6% to 4% and her engagement in learning science increased from 28% to 50%.

Interview results

The interviews with the eight target students, their parents, and science teachers provided more evidence to support the ANCOVA results. Most of these responses indicated improvement on engagement in learning science and argumentation; we present the results from four representative students. Their self-reported improvements on engagement and argumentation were corroborated by comments from their parents and science teachers. For example, Huang rarely engaged in science activities at her regular science class, because it was boring and no fun in there. Through modified ADI teaching

Table 3. Results of ANCOVA of students' engagement in learning science for EG and CG ($N = 72$).

Dimension	Group	*N*	Mean of posttest	*SD*	Adj. posttest mean	Adj. posttest SE	*F*	*p*	η_p^2
ELSS	EG	36	172.31	41.22	172.13	5.70	**4.74**	**.033**	**0.06**
Total scores	CG	36	154.42	34.10	154.59	5.70			
Learning motivation	EG	36	38.97	12.21	38.28	1.81	0.67	.415	0.01
toward science	CG	36	35.47	11.13	36.16	1.81			
Enjoyment in learning	EG	36	34.25	7.44	33.44	1.16	3.24	.076	0.05
science	CG	36	29.64	8.33	30.45	1.16			
Positive feeling toward	EG	36	30.33	8.38	30.29	1.24	1.08	.303	0.02
school	CG	36	28.42	7.13	28.46	1.24			
Anxiety in learning	EG	36	26.50	7.15	26.88	1.28	4.19	**.044**	**0.06**
science	CG	36	23.11	6.11	22.74	1.28			
Self-confidence in	EG	36	18.31	5.08	17.46	0.69	0.20	.657	0.00
learning science	CG	36	16.17	4.49	17.01	0.69			
Pleasure in learning	EG	36	23.94	6.03	23.44	0.96	0.95	.333	0.01
science	CG	36	21.61	6.91	22.11	0.96			

Note: Bold numbers indicate significant differences between EG and CG; small effect size of η_p^2: 0.01; medium effect size of η_p^2: 0.059; large effect size of η_p^2: 0.138 (Cohen, 1988).

Table 4. Results of ANCOVA of students' argumentation between EG and CG ($N = 72$).

Dimension	Group	N	Mean of posttest	SD	Adj. posttest mean	Adj. posttest SE	F	p	η_p^2
Total scores	EG	36	8.61	3.67	8.41	0.48	**10.29**	**.002**	**0.13**
	CG	36	6.03	2.69	6.23	0.48			
Claim	EG	36	3.92	1.30	3.88	0.19	**17.81**	**.000**	**0.21**
	CG	36	2.69	1.04	2.73	0.19			
Evidence	EG	36	1.58	0.97	1.58	0.14	3.65	.060	0.05
	CG	36	1.19	0.82	1.20	0.14			
Warrant	EG	36	2.39	1.02	2.30	0.15	**5.27**	**.025**	**0.07**
	CG	36	1.72	0.94	1.80	0.15			
Rebuttal	EG	36	0.72	0.88	0.71	0.12	2.94	.091	0.04
	CG	36	0.42	0.55	0.43	0.12			

Note: Bold numbers indicate significant differences between EG and CG; small effect size of η_p^2: 0.01; medium effect size of η_p^2: 0.059; large effect size of η_p^2: 0.138 (Cohen, 1988).

approach, she became more engaged in learning science because the instruction provided opportunities for students to cooperate with team members in order to finish a challenging task rather than individual work or cook-book group experiment. Owing to team member's active helps, she also began to be willing to design a method or procedure to investigate science-related phenomenon or issue. Besides, she also actively answers questions or put forward suggestions for others. The target students, teachers, and parents' responses are as following:

Engagement in learning science

Huang (a low engagement in learning science girl) said:

> The science class [modified ADI approach] provided many interesting activities; our team members work together and help each other cooperatively. I am getting involved [in] the hands-on activities and group discussion. I am highly looking forward to attending the science class every week!

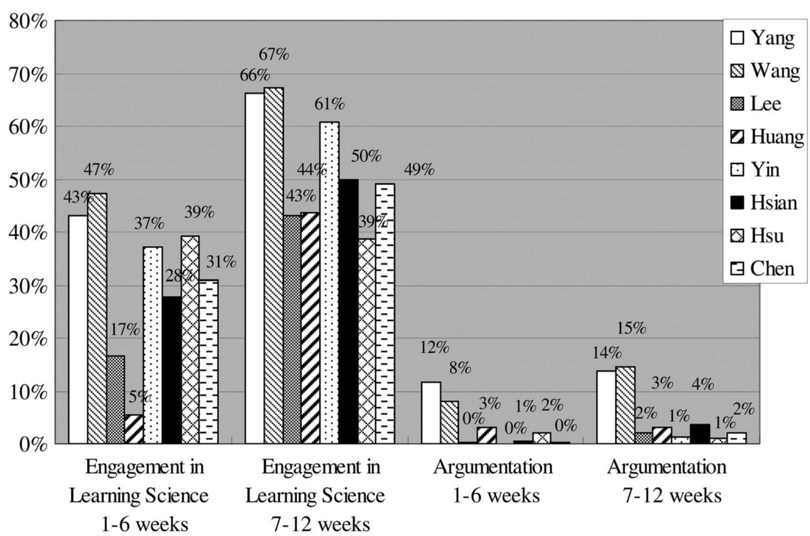

Figure 1. Observation results of the target children.

Huang's science teacher said:

> I found Huang teaches and works with other classmates more friendly attitude this semester, I see that she has changed a lot. She presents a high enthusiasm to engage in manipulating materials and group discussion in my class. In addition, Huang [now] frequently shares her hands-on products with me and classmates.

Huang's mother said:

> From the first day of this science class [modified ADI approach], she highly and actively engaged in the activities, she shared what he had learned from the science class with me, my husband, and her brother. I felt that she was attracted by most of the science activities and topics; I saw that she redid some experiments at home, such as egg protection and candle observation.

Quality level of argumentation

Hsian (a low quality of argumentation girl) said:

> Not only have I learned how to design research questions, make hypotheses, collect data, and provide evidence for a conclusion, but also I learned how to argue with others. For example, during the science class [modified ADI approach], while doing our group presentation in front of the whole class, I can use some argumentation skills, such as making a claim or provide evidence used to support the claim, it was so exciting! I never have experienced learning this from my original science class. This class is really awesome!
>
> Hsian's mother said:
>
> I found Hsian has made a significant improvement in logical thinking and ability of inferring. She has become less negative and emotional during interactions with others. She likes to make a clear claim and provides evidence and data to support her claim while she responses to me or others.
>
> RQ2: What are the differences between the EG and CG students' engagement in learning science and argumentation with different achievement levels?

We conducted an exploratory investigation of distinctive achievement groups to examine differential effects of the modified ADI approach between the EG and CG students. Because there was apparent differences among the sample size of three science grade groups (EG high = 28, EG moderate = 4, EG low = 4; CG high = 19, CG moderate = 7, CG low = 10), we conducted Kruskal–Wallis one-way ANOVA by ranks test to examine differences for different science grades for EG and CG students (Chan & Walmsley, 1997). There were no significant differences on the pretest total scores and subscales of ELSS among the high, moderate, and low science grade groups both for EG and CG students, except for EG students' anxiety in learning science subscale, $\chi^2 = 6.31$, $p = .043$. However, after joining this modified ADI approach, the EG moderate science-grade students outperform the low science-grade students on posttest total scores of ELSS, $\chi^2 = 8.36$, $p = .015$, and on four of the five subscales: learning motivation toward science, $\chi^2 = 8.22$, $p = .016$; positive affection toward school, $\chi^2 = 9.00$, $p = .011$; self-confidence in learning science, $\chi^2 = 6.12$, $p = .047$; and pleasure in learning science, $\chi^2 = 6.23$, $p = .044$. In contrast, there were no differences on the three science grade groups' ELSS posttest scores of the CG.

The same data analyses were used to examine the differences in EG and CG students' argumentation with diverse science grades. No significant differences were found on students' pretest total and component scores of argumentation among different science grade students of EG and CG. However again, the EG high and moderate science-grade students outperform their counterparts of the low science-grade students on posttest total score, $\chi^2 = 8.30$, $p = .016$, and two components of argumentation: claim, $\chi^2 = 8.82$, $p = .012$, and warrant, $\chi^2 = 7.42$, $p = .024$. In addition, the moderate science-grade students perform significantly better than the low science-grade students on the component of evidence, $\chi^2 = 7.20$, $p = .027$. On the other hand, there were no any significant differences on the posttest of the argumentation on the CG students with different grades.

RQ3: What relationships exist within the EG students' ELSS and argumentation?

In order to understand the simple associations between the two dependent variables of engagement in learning science and argumentation, Pearson correlation analyses were conducted. These results confirmed earlier results, that is, the participating EG students' posttest total ELSS positively related to their posttest of argumentation on the total score, $r = .40$, $p < .05$; making a claim subscale, $r = .35$, $p < .05$; providing evidenced data subscale, $r = .38$, $p < .05$; and warranting the relationship between evidence and claim subscale, $r = .45$, $p < .01$. The positive and significant correlation between the two dependent variables reveal that for the EG students regardless of their science-grade level, the more they are engaged in learning science, the better their argumentation performance would be expected.

Discussion and educational implications

The results of the quantitative and qualitative data analyses revealed that the modified ADI approach appeared to enhance the EG students' engagement in learning science and argumentation (RQ1). The EG students significantly outperformed their CG counterparts in their adjusted posttest scores for ELSS, argumentation, and subscales of anxiety in learning science (i.e. significantly less anxiety in learning science), and the argumentation components of claim and warrant. These findings were partially consistent with the literature that showed explicit approaches enhanced students' engagement (Abrahams, 2009; Jenkins, 2011) and argumentation (Hampden-Thompson & Bennett, 2013; Hong et al., 2013).

The analysis revealed a medium–small effect size, $\eta_p^2 = 0.06$, on engagement in learning science total means and a medium effect size, $\eta_p^2 = 0.06$, on anxiety in learning science. Furthermore, the EG students' total means on argumentation, $\eta_p^2 = 0.13$; components of claim, $\eta_p^2 = 0.21$; and warrant, $\eta_p^2 = 0.07$, showed large effect sizes between EG and CG students (RQ1). These results appear to indicate that Grade 4 students' learning motivation, enjoyment, positive feeling toward school, self-confidence, and pleasure in learning science could be more substantial with a lengthier intervention time.

It is not surprising that the EG students' anxiety in learning science was significantly decreased in the intervention since the modified ADI approach is much different from their regular science classes. We provided a big idea (e.g. principles of refraction, electronic repulsion and attraction, buoyancy tension, pendulum, and Boyle's law) in each unit class that focused on broad explanatory power, not trivial details; we paid more attention to encouraging and scaffolding learners understanding the distinctive value of science and prepared them for further learning in science (NRC, 2007). In addition, our study provided learning activities with novelty and aesthetics that related to children's daily lives so that they have tangible reasons for engaging in the modified ADI approach (Chen et al., 2014; Jenkins, 2011; Lin, Hong, Chen & Chou, 2011; Lin, et al., 2013). On the other hand, almost all Taiwanese science teachers are entrenched in a teacher-centered teaching strategy focused on the established body of scientific knowledge that forms the bedrock of the curriculum and science examinations (Chen et al., 2014; Hong et al., 2013). In addition, some elementary school science teachers, who graduated with non-science-related majors, in general, these science teachers highly rely on and follow the textbooks and teacher's guide to determine what they teach, how they teach, and to access their teaching process. Therefore, students must follow step-by-step, cook-book instructions to accomplish the experiments and reach the desired findings without any personal ownership. Furthermore, a traditional grouping might hinder moderate- and low-achieving students from fully engaging in the practical activity and developing the science practices (Chen et al., 2014; Johnson, Johnson, & Holubec, 2008).

It appeared that the student-centered, small-group discussion, supportive environment, peer evaluation, and scaffolding central to the modified ADI approach was very effective for improving the EG students' argumentation on the components of claim and warrant. Almost all of the EG students voiced and demonstrated high involvement in argument activity during this approach. Therefore, these young learners significantly increased their active engagement while significantly decreasing their anxiety in learning science. These findings provide empirical evidence for Driver et al. (2000) dialogical or multi-voiced argumentation model. In addition, the modified ADI approach provided students with active opportunities to learn at their team's pace and to demonstrate and share their new knowledge with other groups of children, regular classmates, and family members. We suggest that elementary school science teachers need to pay more attention to students' argumentation and reasoning instead of simply science knowledge in order to develop their higher level thinking ability essential for citizenship in techno-scientific world.

The moderate-achieving students made much larger gains on the ELSS total means and on the subscale of anxiety in learning science than the high-achieving students. The moderate achievers also made significant improvement on the argumentation total gain means and on the component of claim when compared to the high-achieving students. These results are similar to Hong et al. (2013) study of Grade 5 students' implementation of a science and society approach. One reason that may explain the moderate-achieving students' improvement in their engagement and argumentation is the longer term of intervention that might arouse their *situational interest* gradually becomes an *individual interest* for learning science (Lin et al., 2013). Additionally, the well-structured teaching approach appeared to be much more effective for the EG students (cf. Hsian and Hsian's mother interview results). The modified ADI structure appeared to support moderate achievers in improving their engagement and the quality of argumentation in which they use and evaluate practical science and apply it to their everyday life (Jenkins, 2011). Another reason that may explain the greater effect on the moderate students could be that these students have more flexible, educable, open-minded, or/and extroverted personalities to easily adjust to a new teaching strategy than their high- or low-achieving counterparts (Lin et al., 2011). A third reason is that a low-risk environment and scaffolding were highly supported in the modified ADI approach. The high-achieving students might be used to the traditional teacher-centered teaching strategy for assuring them to obtain honors in their classes; they may believe that the old approach is the best way to learn science since it works for them.

Potential factors why the low-achieving students could not effectively improve their argumentation and decrease their anxiety in learning science might be the modified ADI approach was not focused on writing argumentation skills. Most low-achieving students had low paper–pencil writing ability, but they received some assistance from peers during the modified ADI group activities. Another factor might relate to their families; most were from low-income families, and their parents may not have enough capability, energy, and time to encourage and help them at home (Chen et al., 2014; Hong & Lin, 2011; Hong et al., 2013). Therefore, we suggest that not only oral arguments practice but also guided writing practice in argumentation needs to be provided in elementary school science classes, especially for low-achieving learners who have limited language and writing abilities and insufficient scientific knowledge (Sampson et al., 2013). The researchers suggest that students' emotions [anxiety] about science have considerable effects on engagement in learning science. To clarify, those students who regularly pay more attention to the science activities, in other words who are more behaviorally engaged in lesson tends to show better argumentation performance.

Conclusions and limitations

In summary, the use of quasi-experimental design with Grade 4 students allowed us to shed additional light on the effects of a modified ADI approach. Students were required to engage in science practices: identify and observe a demonstration or presentation of natural phenomena, make research questions and hypotheses, design an investigation procedure and collect data through hands-on activities, provide evidence-based conclusions, and generate argumentation skills. Furthermore, each group shared its argument and then critiqued and refined its explanations and evaluations, which obviously increased the EG students' deep engagement and enhanced their argumentation. Additionally, the moderate science achieving students made large gains on both engagement and argumentation. This study might implicate to science educators and science teachers for fostering these young learners' argumentation ability, and decrease students' anxiety in learning science and on the effects of a modified ADI approach. Moreover, the treatment effect might have been confounded with an attention effect (Austin, 2011). Readers are reminded that, although both EG and CG students were in the same schools and the time spent in class for the two groups was equal, the EG students were volunteers, which may have interacted with the particular features of the approach.

Osborne et al. (2004) claimed that explicit argumentation instruction should be extended over a period of time as part of the science curriculum to achieve a significant importance in students' argumentation. Our study provides clear evidence to support those findings; therefore, implementing guided instruction, such as the modified ADI, for promoting elementary school students' engagement in learning science and argumentation over a long period of time is highly recommended.

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References

Abrahams, I. (2009). Does practical work really motivate? A study of the affective value of practical work in secondary school science. *International Journal of Science Education*, *31*(17), 2335–2353.

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education*, *30*(14), 1945–1969.

Ainley, M., & Ainley, J. (2011). A cultural perspective on the structure of student interest in science. *International Journal of Science Education*, *33*(1), 51–71.

Ainley, M., Hidi, S., & Berndorff, D. (2002). Interest, learning, and the psychological processes that mediate their relationship. *Journal of Educational Psychology*, *94*, 545–561.

Alexander, R. J. (2005). *Towards dialogic teaching: Rethinking classroom talk*. York: Dialogos.

Austin, P. C. (2011). An introduction to propensity score methods for reducing the effect of confounding in observational studies. *Multivariate Behavioural Research*, *46*, 399–424.

Brislin, R. W. (1986). Back-translation for cross-cultural research. *Journal of Cross-cultural Psychology*, *1*(3), 185–216.

Chan, Y., & Walmsley, R. P. (1997). Learning and understanding the Kruskal–Wallis one-way analysis-of-variance-by-ranks test for differences among three or more independent groups. *Journal of Physical Therapy*, *77*, 1755–1762.

Chang, M.-C., Hsieh, H.-Y., & Shyu, C.-Y. (2010). A cognitive component analysis for PISA science literacy. *Curriculum & Instruction Quarterly*, *13*(1), 1–20.

Chen, H.-T, Wang, H.-H, Lin, H. S., Lawrenz, F., & Hong, Z. R. (2014). Longitudinal study of an inquiry-based science camp on low achieving children's affective perceptions of learning science and positive thinking. *International Journal of Science Education*, *36*(13), 2133–2156.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.
Cohen, J. (1994). The earth is round (*p*<.05). *American Psychologist*, *49*, 997–1003.
Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). London: Routledge.
Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(30), 287–312.
Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*, 59–109.
Gilbert, J. K., Bulte, A. M. W., & Pilot, A. (2011). Concept development and transfer in context-based science education. *Science Education*, *33*(6), 817–837.
Grace, M. (2009). Developing high quality decision-making discussions about biological conservation in a normal classroom. *International Journal of Science Education*, *31*(4), 551–570.
Hampden-Thompson, G., & Bennett, J. (2013). Science teaching and learning activities and students' engagement in science. *International Journal of Science Education*, *35*(8), 1325–1343.
Hidi, S. (1990). Interest and its contribution as a mental resource for learning. *Review of Educational Research*, *60*, 549–571.
Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127.
Hong, Z. R., & Lin, H. S. (2011). An investigation of students personality traits and attitudes toward science. *International Journal of Science Education*, *33*(7), 1001–1028.
Hong, Z. R., Lin, H. S., Wang, H.-H., Chen, H.-T., & Yang, K.- K. (2013). Promoting and scaffolding elementary school students attitudes toward science and argumentation through a science and society intervention. *International Journal of Science Education*, *35*(10), 1625–1648.
Hulleman, C. S., & Harackiewicz, J. M. (2009). Promoting interest and performance in high school science classes. *Science*, *326*(5958), 1410–1412.
Jenkins, L. (2011). Using citizen science beyond teaching science content: A strategy for making science relevant to students' lives. *Cultural Studies of Science Education*, *6*(2), 501–508.
Jocz, J., Zhai, J., & Tan, A.-L. (2014). Inquiry learning in the Singaporean context: Factors affecting student interest in school science. *International Journal of Science Education*, *36*(15), 2596–2618.
Johnson, D. W., Johnson, R., & Holubec, E. (2008). *Cooperation in the classroom* (7th ed.). Edina, MN: Interaction Book.
Kahraman, N. (2014). Cross-grade comparison of relationship between students' engagement and TIMSS 2011 science achievement. *Education and Science*, *39*(172), 95–107.
Kind, P., Jones, K., & Barmby, P. (2007). Developing attitudes towards science measures. *International Journal of Science Education*, *29*, 871–893.
Kirk, R. E. (2001). Promoting good statistical practices: Some suggestions. *Educational and Psychological Measurement*, *61*(2), 213–218.
Lee, M.-H., Johanson, R. E., & Tsai, C.-C. (2008). Exploring Taiwanese high school students' conceptions of and approaches to learning science through a structural equation modeling analysis. *Science Education*, *92*(2), 191–220.
Lee, M.-H., Tsai, C.-C., & Chai, C. S. (2012). A comparative study of Taiwan, Singapore, and China preservice teachers' epistemic beliefs. *The Asia-Pacific Education Researcher*, *21*(3), 599–609.
Lin, H. S., Hong, Z. R., Chen, C.-C., & Chou, C. H. (2011). The effect of integrating aesthetic understanding in reflective inquiry activities. *International Journal of Science Education*, *33*(9), 1199–1217.
Lin, H. S., Hong, Z. R., & Chen, Y. (2013). Exploring the development of college students situational interest in learning science. *International Journal of Science Education*, *35*(13), 2152–2173.
Lin, H. S., Hong, Z. R., & Lawrenz, F. (2012). Promoting and scaffolding argumentation through reflective asynchronous discussions. *Computers & Education*, *59*(2), 378–384.
Logan, M. R., & Skamp, K. R. (2013). The impact of teachers and their science teaching on students' 'science interest': A four-year study. *International Journal of Science Education*, *35*(17), 2879–2904.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons*. Melbourne: Australian Council of Learned Academies.
McNeill, K. L. (2011). Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. *Journal of Research in Science Teaching*, *48*(7), 793–823.
Miller, B., Anderson, R. C., Morris, J., Lin, T.-J., Jadallah, M., & Sun, J. (2014). The effects of reading to prepare for argumentative discussion on cognitive engagement and conceptual change. *Learning and Instruction*, *33*, 67–80.
Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Buckingham: Open University Press.
National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.
National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.
National Research Council. (2013). *Next generation science standards*. Retrieved from http://www.nextgenscience.org/next-generation-science-standards
Organization for Economic Co-operation and Development. (2006). *Assessing scientific, reading and mathematical literacy: A framework for PISA 2006*. Paris: Author.
Organization for Economic Co-operation and Development. (2010). *The high cost of low educational performance*. Paris: Author.
Organization for Economic Co-operation and Development. (2014). *PISA 2012 results in focus: What 15-year-olds know and what they can do with what they know*. Paris: Author.
Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections*. London: Nuffield Foundation.
Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020.
Osborne, J., Simon, S., Christodoulou, A., Howell-Richardson, C., & Richardson, K. (2013). Learning to argue: A study of four schools and their attempt to develop the use of argumentation as a common instructional practice and its impact on students. *Journal of Research in Science Teaching*, *50*(3), 315–347.
Patton, M. Q. (2002). *Qualitative evaluation and research methods* (3rd ed.). Thousand Oaks, CA: SAGE.
Pellegrini, A. D. (1996). *Observing children in their natural worlds: A methodological primer*. Mahwah, NJ: Lawrence Erlbaum.
Reznitskaya, A., Anderson, R. C., & Kuo, L. (2007). Teaching and learning argumentation. *Elementary School Journal*, *107*(5), 449–472.
Sampson, V., Enderle, P., Grooms, J., & Witte, S. (2013). Writing to learn and learning to write during the school science laboratory: Helping middle and high school students develop argumentative writing skills as they learn core ideas. *Science Education*, *97*(5), 643–670.
Sampson, V., & Walker, J. P. (2012) Argument-driven inquiry as a way to help undergraduate students write to learn by learning to write in chemistry. *International Journal of Science Education*, *34*(10), 1443–1485.
Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, *28*(2/3), 235–260.
Simon, S., & Johnson, S. (2008). Professional learning portfolios for argumentation in school science. *International Journal of Science Education*, *30*(5), 669–688.
Sjaastad, J. (2012). Sources of inspiration: The role of significant persons in young people's choice of science in higher education. *International Journal of Science Education*, *34*(10), 1615–1636.
Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (4th ed.). Needham Heights, MA: Allyn and Bacon.
Toulmin, S. (1958). *The uses of argument*. Cambridge: Cambridge University Press.
Tytler, R., Symington, D., & Smith, C. (2011). A curriculum innovation framework for science, technology and mathematics education. *Research in Science Education*, *41*, 19–38.

Venville, G. J., & Dawson, V. M. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. *Journal of Research in Science Teaching*, *47*(8), 952–977.

Woods-McConney, A., Oliver, M., McConney, A., Maor, D., & Schibeci, R. (2013). Science engagement and literacy: A retrospective analysis for indigenous and non-indigenous students in Aotearoa New Zealand and Australia. *Research in Science Education*, *43*, 233–252.

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：105 年 9 月 30 日

計畫編號	NSC 102 － 2629 － S － 110 － 001 － MY3		
計畫名稱	以探究論證科學營提升國小女學童情意學習及論證能力之探討		
出國人員姓名	洪瑞兒	服務機構及職稱	國立中山大學教育研究所 特聘教授
會議時間	104 年 8 月 31 日至 104 年 9 月 04 日	會議地點	Helsinki, Finland
會議名稱	The 11th Conference of the European Science Education Research Association (ESERA 2015)		
發表論文題目	Longitudinal study of a cooperation-based SSI intervention on promoting students' critical thinking and self-regulation in learning science		

一、參加會議經過

2015年8月31日至9月4日研究主持人洪瑞兒前往芬蘭赫爾辛基大學參加ESERA 2015 Annual International Conference發表研討會論文，題目為：Longitudinal study of a cooperation-based SSI intervention on promoting students' critical thinking and self-regulation in learning science。會議中除了報告研究過程與結果外，更與來自其他國家的多位發表者(例如：Vaille Dawson、Maralee Mayberry、Marcus Grace、Gerd Johansen、Hsin-Yi Chang），以及來自美國、英國、加拿大、澳洲等多位科教學者，進行互動討論並分享研究心得，獲得許多寶貴收穫。

二、與會心得

本次參與ESERA 2015 Annual International Conference，於口頭發表場次中，提供兩位博士生上台發表的機會，並與他國教育學者相互討論交流，對其未來的研究方向及品質提升有極大的幫助，同時也能夠增進學生英語表達及論文發表能力。而本場次主題關於「社會性科學議題」 (Socioscientific Issue, SSI)，除了本研究團隊之外，還有其他五組關於SSI教學介入或學習評量的口頭發表，該議題在會議中獲得各國學者的關注與許多回應。此外，本次於ESERA 2015研討會中，也與幾位台灣的科教學者們討論目前台灣科學教育的實務與未來發展的可能性，對於本團隊未來研究方向亦有很大幫助。

三、發表論文全文或摘要

Abstract 222 words

Researchers have explored the effectiveness of Socioscientific Issue (SSI) for supporting science teaching and learning in the past three decades. Our guiding presupposition in this study was that SSI instruction could play a role as a vehicle for cultivating junior high school students' character and values as global citizens. The purpose of this research was to determine the benefits of a Cooperation-based SSI intervention to opening up SSI discussion on students' critical thinking and self-regulation in learning science. Forty-nine7th graders were voluntarily recruited to attend a 3-semester intervention and formed the experimental group (EG); another 49 typical 7th graders were randomly selected as the comparison group (CG). The Student Questionnaire (SQ) was administered to assess all participants' critical thinking and self-regulation in learning science. In addition, 4 boys and 4 girls from the EG with the lowest scores on either critical thinking or self-regulation in learning science were selected for observation and interview. Factor analyses, paired- wise t-tests, ANCOVAs, and theme content analyses were used to compare the similarities and differences between the groups and across semesters. An essential result found that the EG students' critical thinking and self-regulation in learning science were gradually and significantly more improved than their counterparts' in the intervention. The results of interviews and observations were consistent with the quantitative findings. Educational implication and recommendation are discussed.

Key words: Secondary school, self-regulation, socioscientific Issues

Summary

1. Rationale of research background

The importance of critical thinking and self-regulation has been emphasized by researchers as the two capabilities are required for scientific literate citizens (e.g., Gokhale, 1995; Zimmerman, 2000). Paul (1995) revealed that critical thinking is a unique and purposeful form of thinking that includes analyzing, evaluating, explaining, and restructuring one's thinking. Ormrod (2009) describes that the "Selfregulation" is a process of taking control and evaluating one's own learning and behavior; which emphasizes autonomy and control by the individual who monitors, directs and regulates actions toward goals. Morris (2014) claimed that Socioscientific Issues (SSIs) in the science curriculum is a well-established trend internationally, which involve the use of science and are of interest to society, also can raise ethical and moral dilemmas. There are plenty of research studies' investigating how SSIs can be used to promote student argumentation, yet little research exists longitudinally examining the development of student critical thinking and self-regulation. Two major research questions are investigated: (1) Do the EG students outperform their counterparts on critical thinking and selfregulation in learning science across three semesters? (2) How effective is the Cooperation- based SSI Intervention on enhancing EG students' critical thinking and self-regulation in learning science.

2. Methods

2.1Design or Procedure

This study took place in Kaohsiung city of Taiwan. The EG consisted of 49 7th graders who were voluntarily recruited to attend a 3-semester intervention; another 49 typical 7th graders of the same school were randomly selected as the comparison group (CG). All students completed 4 times of questionnaire in the beginning of the 1st semester and at the end of the 1st, 2nd and 3rd semesters. In addition, weekly observations and interviews were conducted with target students. Their classroom and science teachers were interviewed at the end of each semester.

2.2Development and Validation of Instruments

2.2.1Student Questionnaire (SQ)

The SQ includes three sections: the 1st section addresses on participants' demographic items; the 2nd section includes 56-item Chinese version of Critical Thinking Scales (CTS) developed by Gupta, Iranfar, Iranfar, Mehraban, and Montaeri (2012). A Brislin's translating and back translating instrument model (1986) was conducted. Then, we perform a confirmatory factor analysis (CFA) to evaluate how well the hypothesized models fit the data of student samples. All the factor loadings are significant (i.e. loadings range from 0.66 to 0.90), and the indexes of fit statistics indicate a good fit to the data ($\chi2(56) = 91.206$, $p = .002$, $\chi2/df = 1.629$, GFI = .901, CFI = .955, RMSEA = .075, PCLOSE = .076). Overall, the results show that the measured model fit the data quite well, and the CTS have an adequate construct validity and internal reliability (Cronbach's $\alpha = 0.80$).

The 3rd section includes 51-item Chinese version of Self-Regulation Questionnaire (SRQ) that developed by Brown, Miller, and Lawendowski (1999). After using the Brislin's translation model, we performed the CFA to evaluate how well the hypothesized models fit of the Taiwanese students. The results showed that all the factor loadings are significant (i.e. loadings range from 0.43 to 0.92), and the indexes of fit statistics indicates a good fit to the data ($\chi2(56) = 190.19$, $p < .001$, $\chi2/df = 3.396$, GFI = .811, CFI = .860, RMSEA = .147, PCLOSE = .000). Overall, the results show that the measured model fit the data quite well, and the SRQ has an adequate construct validity and internal reliability (Cronbach's $\alpha = 0.91$).

2.2.2 Students' classroom observation form

We develop a 7-category 'Classroom Observation Coding Schedule' based on Pellegrini (1996) observational methods to quantify target students' critical thinking and self-regulation in learning science.

2.2.3 Students, classroom and science teachers' interview protocol

A sample interview question for students is: 'Can you describe any changes you experienced while joining this intervention for me?' A sample interview question for classroom and science teachers is: 'Do you perceive and differences in the target student after they attended the intervention?'

2.3 Example of Cooperation-based SSI intervention

A sample is 'Nuclear Power issues'. (1) introduction on the multiple usages of nuclear and thermal power; (2) group discussion on the advantages and disadvantages of the Nuclear Power; (3) hypotheses and assertions: students provide each team's assertions and solutions; (4) debate and conclusion: a large group communication and interaction are implemented.

2.4 Data Analyses

CFA, ANCOVAs, paired-wise t-tests and theme content analyses are used to compare the differences between groups and among semesters.

3. Findings.

RQ1: Do the EG students outperform their counterparts on critical thinking and self-regulation in learning science across three semesters?

The results of ANCOVAs indicate that the adjusted posttest scores of the EG students' mean score on critical thinking is not significantly different from the CG in the 1st semester; whereas, the EG students make a significant improvement than the CG in the 2^{nd} and 3^{rd} semesters. In addition, the adjusted posttest scores of the EG students' self-regulation in learning science are significantly higher than the CG in the 1st and 3rd semesters.

[Insert Figures 1 & 2 about here]

RQ2: How effective is the Cooperation- based SSI Intervention on enhancing EG students' critical thinking and self-regulation in learning science?

We found that the post-test means of the EG students' are significantly higher than their pretest mean scores on critical thinking and three
dimensions of self-confidence on critical thinking ; curiosity toward science, and cognitive understanding. In addition, these EG students' posttest scores on self-regulation in learning science and three dimensions of evaluating the information, searching for options, and assessing are significantly higher than their first semester pretest score across the three semesters.

[Insert Table 1 about here]

4.Education Implication

The quantitative and qualitative results provide support for the feasibility of implementing Cooperation-based SSI intervention to promote students' critical thinking and self-regulation in learning science. It shows the chain of logic is that if students are more engaged in the intervention, their critical thinking was more improved. Interestingly, these EG students' self-regulation improvement indicated a different pattern from the critical thinking. They made a significant improvement in the 1st and 3rd semesters, whereas there was a slight decreased on the 2nd semester. This findings were enlightened an important consideration of how junior high school students' self-regulation in learning science can be continuously enhanced.

5. Reference

Brown, J. M., Miller, W. R., & Lawendowski, L. A. (1999). The Self-Regulation Questionnaire. In L. VandeCreek & T. L. Jackson (Eds.), Innovations in clinical practice: A source book (pp. 281-289). Sarasota, FL: Professional Resource Press.

Brislin, R.W.(1986). The Wording and Translation of Research Instruments. In W.L. Lonner and J.W.Berry, eds Field Methods in Cross-Cultural Research. Newbury Park, CA: Sage.

Gokhale, A. A. (1995). Collaborative Learning Enhances Critical Thinking Journal of Technology Education, Fall, 7(1).

Karuna Gupta, Shirin Iranfar, Khosro Iranfar, Bahamn Mehraban, & Nosrtollah Montazeri(2012). Validly and reliability of California critical thinking disposition inventory (CCTDI) in

Kermanshah university of medical sciences. Educational Research in Medical Sciences, 1(1), 61- 68.
Morris (2014). Socioscientific issues and multidisciplinarity in school science textbooks. International Journal of Science Education, 36(7), 1137–1158.
Ormrod (2009). Educational Psychology: developing learners (7th ed.). Upper Saddle River, NJ. Pearson-Prentice Hall.
Paul, R. W. (1995). Critical Thinking: How to prepare students for a rapidly changing world. Santa Rosa, CA: Foundation for Critical thinking.
Pellegrini, A.D. (1996). Observing children in their natural worlds: A methodological primer. Mahwah, NJ: Lawrence Erlbaum.
Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich & M. Zeidner (Eds). Handbook of Self-regulation, Amsterdam: Elsevier.

四、攜回資料名稱及內容

ESERA 2015 國際教育研討會手冊

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：105 年 9 月 30 日

計畫編號	NSC 102 － 2629 － S － 110 － 001 － MY3		
計畫名稱	以探究論證科學營提升國小女學童情意學習及論證能力之探討		
出國人員姓名	洪瑞兒	服務機構及職稱	國立中山大學教育研究所 特聘教授
會議時間	105 年 4 月 14 日至 105 年 4 月 17 日	會議地點	Baltimore, MD, USA
會議名稱	National Association for Research in Science Teaching (NARST) 88th Annual Conference		
發表論文題目	The investigation of effective strategies for developing creative science thinking		

一、參加會議經過

2016年4月14日至4月17日研究主持人洪瑞兒前往美國巴爾的摩Renaissance Baltimore Harborplace Hotel參加NARST 2016 Annual International Conference發表研討會論文，題目為：The investigation of effective strategies for developing creative science thinking。會議中除了報告研究過程與結果外，更與來自美國Specialist Elementary Teachers, North Carolina State University, Western Washington University,University of Iowa等多位發表者（例如：Joseph A. Brobst, Courtney Nelson Plumley, Jee Kyung Suh與David E. McKinney）相互交流，獲得許多寶貴建議。

二、與會心得

NARST Annual International Conference是美國歷史悠久且規模相當大的科教國際研討會，提供給各國科教學者一個良好的平台相互交流，其投稿文章審核方式相當嚴謹且審查標準偏高，在這次口頭發表場次中，本團隊僅有一位博士生有機會隨同上台發表，與他國教育學者相互討論交流，甚為可惜。因此，鼓勵學生未來多嘗試合作投稿，讓更多學生能夠一同前往參與發表討論，對培育未來的學術人才亦將更有助益。

三、發表論文全文或摘要

Abstract

The purpose of this study was to explore the effectiveness of the Creative Inquiry-based Science Teaching (CIST) on students' creative science thinking and science inquiry performance. A quasi-experiment design consisting one experimental group(N =20) and one comparison group(N= 24)with pre- and posttests was conducted. The framework of the intervention focused on potential strategies recommended by literature. Results reveal that the experiment group students outperform their counterparts on the performances of science inquiry and convergent thinking. Additional

qualitative data analyses from classroom observations and case teacher interviews allow us identify supportive teaching strategies of developing student creative science thinking.

Keywords: science inquiry, convergent thinking, divergent thinking

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 (Dehann, 2011). 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 taught through well-designed training programs (Scott, Leritz, & Mumford, 2004). In addition to the cognitive approach, Bull, Montgomery, and Baloche (1995) recommended that motivational approach and social interactional approach could also be supportive in promoting student performance of creativity. Insights gained from the above literature reveal that designing theory-based intervention to develop creativity performance and examining its effectiveness are critical and feasible. However, what remain relatively poorly understood are the key characteristics and details of effective interventions that influenced the success of developing student creativity performance. As Kind and Kind (2007) recommended, further research agenda of 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.

The importance of science inquiry has been emphasized in national curriculum or national science education standards (National Research Council, 1996, 2000). Teachers are being encouraged to engage students in authentic scientific investigations of making hypothesis, designing experimental procedure, and interpreting data and evidence rather than focusing narrowly on the learning of content knowledge and concepts (Morrison, 2014). Taylor, Jones, Broadwell, and Oppewal (2008) also concluded that the majority of scientists and science teachers 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. Along similar lines, Dehann (2011) pointed 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). In view of the gap between the goal set by national science education standards and typical status of science teaching practices, it reveals that developing teaching material for higher-order creative science thinking (Kind & Kind, 2007) and training teacher professional development (Authors, 2013) have become important aspects of science education. However, existing literature has limited understanding about how or if the practices of science inquiry have any potential to enhance student creative science thinking. Therefore, this study is intended to develop theory-based teaching material and examine its effects of promoting student scientific creativity especially on creative science thinking. The following two research questions guided our study: (1) What is the impact of CIST on students creative science thinking and science inquiry performance？(2) What teaching methods are supportive of student's reflection on divergent and convergent thinking?

Method

Participants and settings

An experienced inquiry-based science teaching teacher, Ron, and 44 students were asked to participate in this quasi-experimental study. Ron has 10.5 years of teaching experience and been trained and involved in inquiry-based science teaching for four years. He was in charge of teaching science subject for all classes of grade 5 in the school. Among these classes, one class was randomly selected as the experimental group (N = 20). Another class of grade 6 students (N = 24) taught by a teacher with similar background with Ron was selected as the comparison group.

Instruments and Intervention

Two instruments - the science inquiry test and the scientific creativity test that have been previously validated with satisfactory reliability and validity were used in this study (Authors, Under review).

Creative Inquiry-based Science Teaching (CIST). Ron was trained to conduct the intervention by one session of 1-hour workshop training and three times of 1-hour round table discussions. The workshop training was focused on the introduction of creative science thinking instruction. Professional journal articles explaining the framework of creative science thinking (Dehann, 2011) and sample teaching lessons were used as discussion materials. Four instructional units (i.e., aqueous solution, force and motion, astronomy, combustion) were designed. The framework of inquiry is focused on questioning, planning, implementing, concluding and reporting (Cuevas, Lee, & Hart, 2005) while the framework of creative science thinking is focused on divergent and convergent thinking (Dehann, 2011). Students were encouraged to proposing multiple research methods to solve the ill-structured problem (i.e., divergent thinking) through small group discussion; each group was encouraged to evaluate strengths and weaknesses of their proposals and make a group consensus to select the best proposal for further exploration. At the end of their exploration, students were encouraged to identify the key independent variables influencing the result of their experiment through group discussion (i.e., convergent thinking).

Data collection and analysis

Both groups responded the science inquiry test and scientific creativity test for the pre- and posttests. The experimental group students participated in a 16-week CIST lessons while the comparison group students attended the same time of instruction with regular and typical science teaching. Researchers observed and video-recorded case study teacher teaching practices and organized informal discussions at the end of each lesson. Ron was interviewed to elaborate his teaching goal and teaching methods as well. Continuing formal and informal interviews, researchers' on-site visit field notes, students' worksheets and teacher's lesson plans were used to consolidate what teaching methods were used to supporting students' creative science thinking.

Results

Analysis of covariance (ANCOVA) was conducted to compare the differences between groups on the inquiry performance and creative science thinking. As shown in Table 1, the experimental group students outperformed their counterparts on the performances of science inquiry and convergent thinking. Additional paired-samples *t*-tests revealed that the experimental group students made significant progress on the performances of science inquiry(p = .025) and divergent thinking(p = .027), while the comparison group made no significant changes on these assessments.

Table 1 *Result of ANCOVAs of student's creative science thinking and Science inquiry performance between experiment and comparison groups(A: Experiment group; B: Comparison group)*

Construct	**Groups**	***N***	**Pretest**			**Posttest**			**Adjusted posttest**		***F***	***p***	***ES*(η^2)**
			M	***SD***	***SE***	***M***	***SD***	***SE***	***M***	***SE***			
Creative Science thinking[b]	EXP[a]	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: EXP: experimental group; COM: comparison groups
b: scores of creative science thinking (0 to 70 points; 9 items); divergent creativity (0 to 66 points; 7 items); convergent creativity (0 to 4 points; 2 items); science inquiry(i.e., O-inquiry and M-inquiry: 0 to 41 points ; 7 open-ended items and 24 multiple choices items);

Open-coding procedures were used to identify categories in the data that reflected case study teachers' teaching methods about supporting student's reflection on divergent and convergent thinking. Coding procedures were done by two coders, they examine and re-examine all data until they reach consensus in assigning categories. We present the findings according to two major aspects: divergent and convergent thinking (as table 2). The main supporting teaching methods on divergent thinking could be identified as: facilitating associative thinking, and sharing impressive ideas; On the other hand, the main supporting teaching methods on convergent thinking were covered as: encouraging evident base conclusion and reviewing and commanding in group presentation.

Table 2 *Teachers' teaching methods that are supporting student's creative thinking in divergent and convergent thinking*

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

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 on creative science thinking. Although additional studies are needed to confirm practical utility, the initial findings provide empirical evidence to confirm the effectiveness and feasibility of promoting student creative science thinking through classroom teaching. As empirical studies of exploring student 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 try other theory-based learning materials or instructional strategies.

The second noteworthy finding from this study is that effective strategies of developing divergent and convergent thinking have been identified respectively through qualitative data of classroom observations along with interviews. Previous literature indicates that new model and hypothesis are most often generated through interactions and discussions among knowledgeable scientists (Dehann, 2011). 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 make progress on divergent and convergent thinking. It is encouraging to see the beginning science learners engaged in active collaboration of identifying and controlling variables, planning investigation procedures, collecting and analyzing data, and presenting and communicating result like typical scientists do in laboratory. It is hoped that the identification of effective teaching strategies opens a window to allow future studies develop and confirm ways of promoting student creative science thinking.

It should be noted that effective teaching strategies in promoting creative science thinking are many and varied. The fruitful findings and 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.

Reference

Authors. (2013). *International Journal of Science Education*.

Authors. (Under review). *Creativity Research Journal*.

Bull, K. S., Montgomery, D., & Baloche, L. (1995). Teaching creativity at the college level: A synthesis of curricular components perceived as important by instructors. *Creativity Research Journal, 11*, 123-150.

Cuevas, P., Lee, O., & Hart, J. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching, 42*(3), 337-357.

Dehann, R. L. (2011). Teaching creative science thinking. *Science, 334*, 1499-1500.

Kind, P. M., & Kind, V. (2007). Creativity in science education: Perspectives and challenges for developing school science. *Science Education, 43*(2007), 1-37.

Morrison, J. A. (2014). Scientists' participation in teacher professional development: the impact on fourth and eighth grade teachers' understanding and implementation of inquiry science. *International Journal of Science and Mathematics Education, 12*(4), 793-816.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy of Science.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy of Science.

Scott, G., Leritz, L. E., & Mumford, M. D. (2004). The effectiveness of creativity training: A Quanitative review. *Creativity Research Journal, 16*(4), 361-388.

Taylor, A. R., Jones, M. G., Broadwell, B., & Oppewal, T. (2008). Creativity, inquiry, or accountability? Scientists' and teachers' perceptions of science education. *Scence Education, 92*, 1058-1075.

四、攜回資料名稱及內容

NARST 2016 國際教育研討會手冊

科技部補助計畫衍生研發成果推廣資料表

日期:2016/10/11

<table>
<tr><td rowspan="3">科技部補助計畫</td><td>計畫名稱: 以探究論證科學營提升國小女學童情意學習及論證能力之探討</td></tr>
<tr><td>計畫主持人: 洪瑞兒</td></tr>
<tr><td>計畫編號: 102-2629-S-110-001-MY3　　　學門領域: 性別與科技研究</td></tr>
<tr><td colspan="2">無研發成果推廣資料</td></tr>
</table>

102年度專題研究計畫成果彙整表

計畫主持人：洪瑞兒					計畫編號：102-2629-S-110-001-MY3		
計畫名稱：以探究論證科學營提升國小女學童情意學習及論證能力之探討							
成果項目					量化	單位	質化（說明：各成果項目請附佐證資料或細項說明，如期刊名稱、年份、卷期、起訖頁數、證號...等）
國內	學術性論文	期刊論文			0	篇	
		研討會論文			0		
		專書			0	本	
		專書論文			0	章	
		技術報告			0	篇	
		其他			0	篇	
	智慧財產權及成果	專利權	發明專利	申請中	0	件	
				已獲得	0		
			新型/設計專利		0		
		商標權			0		
		營業秘密			0		
		積體電路電路布局權			0		
		著作權			0		
		品種權			0		
		其他			0		
	技術移轉	件數			0	件	
		收入			0	千元	
國外	學術性論文	期刊論文			0	篇	
		研討會論文			1		Chen, H-T., Wang, H-H., & *Hong, Z. R. (2016). Longitudinal Impact of a Cooperative Inquiry-based Learning on Children's Images towards Scientists and Scientific Self-efficacy. Paper was accepted by The 5th Biennial Conference of East-Asian Association for Science Education (EASE), Tokyo University of Science, Tokyo, Japan, 8/26~8/28, 2016.
		專書			0	本	
		專書論文			0	章	
		技術報告			0	篇	
		其他			0	篇	
	智慧財產權及成果	專利權	發明專利	申請中	0	件	

				已獲得	0		
			新型/設計專利		0		
		商標權			0		
		營業秘密			0		
		積體電路電路布局權			0		
		著作權			0		
		品種權			0		
		其他			0		
	技術移轉	件數			0	件	
		收入			0	千元	
參與計畫人力	本國籍	大專生			0	人次	
		碩士生			1		擔任課室觀察員、問卷建檔
		博士生			2		實施實驗教學、分析資料與撰寫研究報告
		博士後研究員			0		
		專任助理			0		
	非本國籍	大專生			0		
		碩士生			0		
		博士生			0		
		博士後研究員			0		
		專任助理			0		

其他成果 （無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。）	無

	成果項目	量化	名稱或內容性質簡述
科教國合司計畫加填項目	測驗工具（含質性與量性）	4	科學學習參與量表、論證能力測驗、課室觀察表、半結構式國小學童訪談大綱
	課程/模組	1	MADI課程模組
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

科技部補助專題研究計畫成果自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現（簡要敘述成果是否具有政策應用參考價值及具影響公共利益之重大發現）或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以100字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形（請於其他欄註明專利及技轉之證號、合約、申請及洽談等詳細資訊）

論文：□已發表 □未發表之文稿 ■撰寫中 □無

專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以200字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性，以500字為限）

本研究目的在於探討高雄市國小學童參加為期三年的探究論證科學營，藉由MADI探究論證教學模式，激發國小學童的科學情意學習及提升學童探究及論證能力之成效。本研究邀請到36位國小四年級學童作為實驗組進行為期兩年的探究論證科學營教學活動，且於該校同年級學生中選取兩班83名國小學童作為對照組。三年研究期間持續比較實驗組與對照組學生在科學情意學習、探究及論證能力的差異性與共通性。第一年研究發現，國小女學童在學習焦慮已明顯低於對照組，而論證能力在提出主張與論述層面有顯著提升；第二年研究發現國小女學童的科學參與的樂趣與愉悅感顯著提升，而論證能力的四個層面均有顯著進步。第三年則發現除了論證能力持續進步之外，學生的科學自我效能亦有顯著提升，顯示學生更有科學自信，相信自己有能力完成難度較高的科學活動並能夠與同儕討論分享。因此，本研究對於提升國小學生的科學情意學習、探究及論證能力均有具體成效，研究成果將可提供資訊作為未來相關研究之參考。

4. 主要發現

本研究具有政策應用參考價值：□否 ■是，建議提供機關國小教育應開始重視探究與論證式教學，以提升學生自然探究與論證等高層次思考能力，並增加科學參與意願。

（勾選「是」者，請列舉建議可提供施政參考之業務主管機關）
本研究具影響公共利益之重大發現：■否　□是
說明：（以150字為限）
無