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Using a modified argument-driven inquiry to promote elementary school students' engagement in learning science and argumentation

Hsiang-Ting Chen, Hsin-Hui Wang, Ying-Yan Lu, Huann-shyang Lin and Zuway-R Hong

Institute of Education, National Sun Yat-sen University, Kaohsiung, Republic of China

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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KEYWORDS
Argumentation; elementary students; engagement in learning science; modified argument-driven inquiry; Taiwan

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

CONTACT Zuway-R Hong a3803429@gmail.com Institute of Education, National Sun Yat-sen University, 18-1 F No.5, Cheng Hsin Road, San Ming District, Kaohsiung 80702, Taiwan, Republic of China

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!

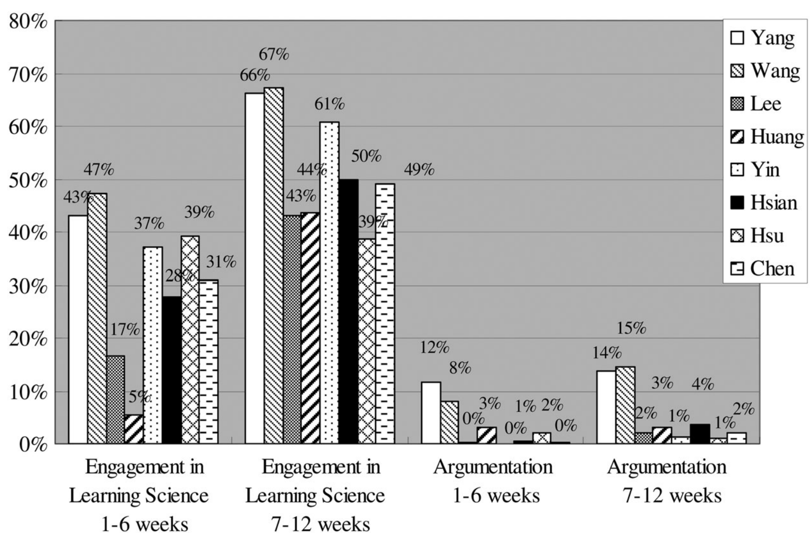

Figure 1. Observation results of the target children.

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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Notes on contributors

Hsiang-Ting Chen is a Ph.D. candidate in the Institute of Education at the National Sun Yat-sen University, Taiwan. Her research interest focuses on inquiry and argumentation in learning science.

Hsin-Hui Wang is a Ph.D. candidate in the Institute of Education at the National Sun Yat-sen University, Taiwan. Her research interests focuses on socio-scientific issues and inquiry teaching and learning.

Ying-Yan Lu is a Ph.D. student in the Institute of Education at the National Sun Yat-sen University, Taiwan. Her research interests focuses on inquiry and moral education.

Huann-shyang Lin is a chair professor at the National Sun Yat-sen University, Taiwan. His current research explores the interplay between affective factors and students' learning outcomes.

Zuway-R Hong is a professor at the Institute of Education, National Sun Yat-sen University, Taiwan. Her research interests focuses on affective learning and inquiry teaching in learning science.

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