



Abstract. *The research aim was to examine the effects of a Critique-Driven Inquiry (CDI) intervention on primary and secondary school students' critical thinking and scientific inquiry competency. Twenty-five 4th grade Taiwanese students from a typical primary school were selected to participate in experimental group 1 (EG1), while 28 7th grade students from a typical secondary school were randomly selected to participate in experimental group 2 (EG2). For each group, a 2-semester CDI intervention was implemented. In addition, another 28 4th graders and 30 7th graders from the same two schools were selected to participate in, respectively, control group 1 (CG1) or control group 2 (CG2). Analyses of covariance, repeated measures analysis of variance, and content theme analyses were conducted to analyze the quantitative and qualitative data. Research results indicated that EG1 and EG2 students significantly outperformed their comparison counterparts in critical thinking and scientific inquiry competency both during and following the CDI intervention. The empirical evidence provides insight into the mechanisms of promoting primary and secondary school students' critical thinking and scientific inquiry competency.*

Keywords: *critical thinking, critique-driven inquiry (CDI), primary and secondary school students, scientific inquiry competency, Taiwan*

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THE EFFECTS OF CRITIQUE-DRIVEN INQUIRY INTERVENTION ON STUDENTS' CRITICAL THINKING AND SCIENTIFIC INQUIRY COMPETENCY

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Introduction

In this information-rich 21st century society characterized by rapid expansion of knowledge, one of the important goals in science education is to cultivate students' critical thinking and inquiry competency (Jenkins, 2011; National Research Council [NRC], 2012; Organization for Economic Co-operation and Development [OECD], 2017). Critical thinking is the essential capacity to evaluate problem-solving procedures, justify arguments, and make educated decisions (Yang & Chung, 2009). The NRC (2012) has suggested that critical thinking is necessary for engaging in inquiry-based science activities, whether in proposing research questions, conducting empirical studies or developing explanation and solutions. Lee et al. (2013) found that students who engaged in cooperative learning and communicative interaction with team members could improve their critical thinking skills. Furthermore, Henderson et al. (2015) emphasized the importance of critical thinking, and provided guidance in how to develop these skills from both the instructor's and learner's perspectives. Thus, promoting students' critical thinking becomes a primary focus for science educators.

The National Research Council (NRC, 1996) and American Association for the Advancement of Science (AAAS, 1993) both have emphasized the importance of scientific inquiry as the ideal approach for students to enhance their science content and practice understanding in authentic context. Inquiry-oriented teaching and learning is widely agreed-upon as an effective approach for improving students' learning outcomes (Chen et al., 2016; Chen et al., 2019; Chi et al., 2018; Lederman et al., 2013; Yang et al., 2016). To ensure that students in all grade levels and within all science related domains think and act in ways associated with scientific inquiry, promoting scientific inquiry competency is recommended by the NRC (1996). In addition, to improve students' engagement with science inquiry related practices and thinking skills, the National Science Education Standards (NSES) recommends that science teachers design scientific inquiry curriculum for students to familiarize them with how scientists explore the natural world

(National Research Council [NRC], 2000). Although considerable extant research has emphasized the importance of students' science learning outcomes (e.g. Jenkins, 2011), limited attention has been focused on how to improve students' critical thinking and their scientific inquiry competency through effective teaching strategies. Based on the suggestions of the previously-mentioned national reports (AAAS, 1993; NRC, 1996; NRC, 2000) and research results, we designed a two-semester long Critique-Driven Inquiry (CDI) Intervention and examined its impact on students' critical thinking and scientific inquiry competency.

Significance of Critical Thinking in Students' Science Learning

Critical thinking is seen as a metacognitive process that consists of several sub-skills such as memory, comprehension, analysis, evaluation, inference, and reflective judgement. Individual argumentation and problem-solving abilities can be improved when critical thinking is appropriately used (Dwyer et al., 2014). Critical thinking is important in educational settings because it can help students to gain a more complex understanding of the information being presented to them (Dwyer et al., 2012). Moreover, some researchers have found that critical thinkers make wise decisions and reasonable judgements when they encounter complicated problem-solving situations (Butler et al., 2012) and, in the development of such skills, they gradually become informed and active citizens (Barton & McCully, 2007) that is essential to develop. Both the NRC (2012) and OECD (2017) have posited that critical thinking is a crucial skill in contemporary science learning. Critical thinking skills make students more capable of understanding the scientific process and may enhance their ability to ask high quality questions in science classrooms (Tsai et al., 2013). The abilities to think critically and ask questions are the basis of independent learning and inquiry, which is why they are vitally important for students (Jiang & McComas, 2015). In the domain of science, ideas compete with each other to determine which offers the best or most appropriate explanation for a particular phenomenon—a process that is carried out through peer review and critique. In light of this, critical thinking becomes essential for students to effectively engage in scientific inquiry and solve problems that they confront both in their school setting and in their daily lives (Abrami et al., 2008; Dwyer et al., 2014; NRC, 2012).

Previous studies have demonstrated that critical thinking can be used in a variety of different science learning activities. For example, critical thinking helps students identify potential flaws in scientific ideas and identify why a specific answer is incorrect (Henderson, et al., 2015; NRC, 2012; Swartz & McGuinness, 2014). In addition, through the process of constructing and critiquing intervention procedures and results, students can learn how science knowledge is constructed and accepted by the science community (Ford, 2012). Finally, critical thinking can be integrated into the learning activities of scientific inquiry, which include: 1) identifying different propositions and understanding the differences between conclusion, premises, and reasons in an argument; 2) evaluating arguments from multiple aspects (e.g. the credibility, logical strength or imbalance); and 3) arriving at a reasonable conclusion based on premise evaluation (Dwyer et al., 2014; NRC, 2012).

Scientific Inquiry Competency and Inquiry-based Learning Activity

Explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically currently are viewed as three core student competences (OECD, 2017). For scientists, inquiry is one way of developing new knowledge and understanding how scientific knowledge generated and accepted. For nonscientists, however, inquiry is an ability used not only to understand science, but also to solve problems they encounter in their daily lives (Lederman et al., 2013; NRC, 2012).

Although scientific inquiry is important, there is no easy way to become scientifically literate within a brief amount of time. Students may miss key points when conducting inquiry process (Sampson et al., 2009; Wong & Hodson, 2010). For example, the skill of connecting evidences and claims to convince peers can be problematic for students (Sampson et al., 2009; Wong & Hodson, 2010). In addition, elaborating on their conclusions is not easy for students when discussing their claims (Chen et al., 2016). Hence, it's important to develop inquiry-based teaching approaches that effectively promote students' scientific inquiry competency (Bass et al., 2009; Howes et al., 2009).

In spite of this recognized need, determining which essential practices should be included in inquiry-based learning activities remains unclear (Rönnebeck et al., 2016). The framework of NRC (2012) for K-12 science education states that the inquiry process includes observation, measurement, experimentation, and data collection (Aslan, 2019; Jiang & McComas, 2015; NRC, 2012). On the other hand, Capps et al. (2016) provided a 7-dimensional framework of scientific inquiry that includes questioning, interpreting data, explaining evidence, arguing, communicating, and modeling.



In the present research, a 20-unit, 40-hour scientific inquiry activity (ten, 2-hour units each semester) was designed and delivered over the course of two semesters. Within the experimental group, the primary element of critical thinking was integrated into the teachers' teaching practices through lectures, demonstration, and hands-on experiments that provided students with varied learning opportunities. These learning opportunities utilized information from contextual connecting sources to connect explanations and scientific knowledge, and allowed students to design experiments, analyze and interpret findings, present small group conclusions or results, provide and respond to peer-comments and critiques, and brain-storm about group projects.

CDI Teaching for Student's Science Learning

In order to cultivate students' scientific inquiry competency, many different instructional approaches have been suggested. Among them, Argument-Driven Inquiry (ADI) is a unique teaching approach that helps science teachers transfer a traditional experiment into a short instructional unit (Sampson et al., 2009). Within ADI, argumentation structure is viewed as consisting of distinct components such as identifying a task, producing a tentative argument report, revising the report, and sharing and discussing with peers. The advantage of ADI is that it gives students a clear framework to construct arguments (Ford, 2012). Although, many researchers have focused on exploring the effects of inquiry in learning science (e.g., Osborne & Dillon, 2008), limited attention has been focused on understanding how best to enhance learners' scientific inquiry competency, an essential component of scientific literacy recommended by the OECD (2017). Sampson et al.'s ADI approach enables the transformation from a traditional laboratory activity to a short-term integrated instructional unit. Furthermore, a Modification of Argument-driven Inquiry (MADI) teaching approach (Chen et al., 2016) and Supportive Argument-driven Inquiry (SADI) intervention (Chen et al., 2019) have been found to show positive effects on students' engagement and argumentation.

As previously mentioned, critical thinking is important when conducting scientific inquiry. It helps students identify, evaluate, analyze, reflect, and adjust the processes they conduct (Dwyer et al., 2014). In the present research, we incorporated a component of critical thinking into the teaching approach, resulting in a new approach that we refer to as the Critique-Driven Inquiry (CDI) teaching approach. It focuses on providing learning opportunities for students to think critically through a series of scientific inquiry activities. In the development of science knowledge, peer-review is a necessary procedure for scientists to test novel ideas and construct of new knowledge. The research hypothesized that peer-assessment and critique would support the development of student scientific inquiry competency because critique can help students identify the deficiency of their arguments and revise their claims accordingly (Ford, 2012; Mercier & Sperber, 2011). As critique is essential for students in science learning, a variety of teaching approaches have been proposed to help students build this skill. For example: Chen et al. (2016) indicated that how the Science Writing Heuristic (SWH) approach promoted fifth grade students' critique ability. Their results showed that students were able to effectively critique following the intervention. Another approach that focuses on critical thinking and practical skill is called the orientation/ decision/do/ discuss/reflect (OD3R) method, and has been shown to improve college students' critical thinking (Anwar et al., 2018). Furthermore, Ghanaat Pisheh et al. (2019) found that student response systems (SRSs), which are personal response systems used to pose questions and gather students' responses during a lecture, can be used as an intervention to cultivate eighth grade students' critical thinking ability.

Instead of exerting direct effects, social cognitive theory (Bandura, 1986) posits that environmental factors are more likely to influence a person's behavior indirectly through self-beliefs (e.g., self-efficacy, self-concept). Additionally, they are a good way for students to raise learning interest and enjoyment through involvement in science activities (Bamberger & Tal, 2007). When learning in inquiry-oriented science learning environments, learners have increased opportunity to interact actively with teachers and/or peers, therefore it is beneficial to foster positive effects on affective factors and cognitive thinking in learning science (Chen et al., 2019). However, there is a lack of empirical research in this area, particularly for beginning learners and intermediate-age students. Therefore, in this research, we focused on integrating the critique element into inquiry-based science teaching activities using an approach that is called Critical-Driven Inquiry (CDI) to examine if well-designed activities can positively impact the critical thinking and scientific inquiry competency of both primary and secondary school students.

Research Aim and Research Questions

Existing literature indicates that, in Taiwan primary and secondary school settings, science teachers focus much more on content knowledge than other elements such as the clarification, evaluation, and justification toward a



science issue or phenomenon s (Chen et al., 2016; Lee et al., 2012). In addition, Taiwanese science teachers typically are unfamiliar with argumentation and inquiry teaching approaches, and this lack of familiarity may restrict students' critical thinking development and scientific inquiry competency. In order to offer more inquiry-oriented learning opportunity, the aim of this research was to develop an innovational teaching approach of Critique-Driven Inquiry (CDI), and to explore its effects on young learner's critical thinking as well as their scientific inquiry competency. Therefore, three research questions were posed:

- 1) What are the effects of CDI intervention on students' critical thinking and scientific inquiry competency?
- 2) How did the primary and secondary school students' critical thinking and scientific inquiry competency change across the 2-semester research period?
- 3) What is the impact of CDI intervention on primary and secondary school students' critical thinking and scientific inquiry competency?

Research Methodology

General Background

A quasi-experimental intervention design was used in this research, carried out in Taiwan during the 2019 school year. For EG students, a 20-week CDI intervention (two hours per week, for a total of 40 hours) was implemented over the course of two semesters, while the CG students participated in their regular science lessons within their classrooms for the same duration. Invitation emails and consent forms were sent to participants requesting their agreement to participate in the research. Student questionnaire data were collected at three time points: at the beginning of the first semester (pre-test), at the end of the first semester (post-test 1), and at the end of the second semester (post-test 2) to assess participants' learning progress and changes in their critical thinking and scientific inquiry competency. Guidance to the students was provided in the questionnaire. If a student had any question while responding to the questionnaire, their instructor was available to explain the statements to the students to help them complete the tasks. All of the students in the research were assured that their responses would be held confidential. In addition, a total of 16 target students were observed weekly and interviewed for 30-40 minutes after each semester's intervention to triangulate assessment of the critical thinking and scientific inquiry competency performance of students in the experimental group (EG).

Participants and Setting

This research was undertaken in one typical primary school and one typical secondary school in southern Taiwan (Kaohsiung City). Participants in experimental group 1 (EG1) consisted of 25 4th graders (13 males, 12 females) while experimental group 2 (EG2) included 28 7th graders (15 males, 13 females), where the students were selected to participate in a 20-week, 40-hour CDI intervention (2 hours per unit) delivered over the course of two semesters. Two control groups also were formed, consisting of 28 4th graders (CG1; 16 males, 12 females) and 30 7th grade students (CG2; 15 males, 15 females) who were selected from the same two schools, and these students were taught using regular science teaching practices. All participants completed a pre-test questionnaire at the beginning of the first semester, and two subsequent post-test questionnaires (post-test 1 and post-test 2) at the end of each semester. In addition, 8 4th graders from the EG1 and 8 7th graders from EG2 with either the highest pre-test scores or the lowest pre-test scores in critical thinking or in scientific inquiry competency were purposively recruited for weekly observation and each of these students participated in an interview conducted by the researchers at the end of each semester. The informed consent from teachers, parents, and students for each aspect of the research (survey, intervention, observation, and individual semi-structured interview) was requested, and the research was approved by the research ethics committee to ensure its ethical soundness.

Instrument and Procedures

Student Questionnaire (SQ)

The Student Questionnaire (SQ) included three sections: demographic items, the Critical Thinking Scale (CTS), and the Scientific Inquiry Competency Test (SICT).



The first section of the SQ consisted of respondent demographics (gender, age, science). The second section of the SQ included a modified 27-item Chinese version of Critical Thinking Scale (CTS), which was based on translated version of the original California Critical Thinking Disposition Inventory (CCTDI; P. A. Facione, & Facione, 1992) developed and validated by Yeh (2002). Total scores were computed as the sum of the 27 four-point Likert items, where a higher score indicated a higher level of critical thinking. To assess validity evidence for the CTS, the results of principal components analysis (PCA) were carried out. The data were deemed appropriate for such analysis (Kaiser-Meyer-Olkin Measure of Sampling Adequacy = .785, $p < .001$). The results from the PCA revealed 5 components accounting for 58.33% of the total variance. The first factor (*Analytical skills*) included 7 items that accounted for 14.86% of the variance; the second factor (*Problem-oriented thinking*) included 5 items that accounted for 14.60% of the variance; the third factor (*Open-mindedness*) included 8 items that accounted for 10.99% of the variance; the fourth factor (*Self-confidence*) included 4 items that accounted for 9.48% of the variance; the fifth factor (*Truth-seeking*) included 3 items that accounted for 8.40% of the variance. Overall scores from the CTS demonstrated good internal consistency (Cronbach's $\alpha = .86$) and the reliability coefficients for each subscale were .84, .85, .76, .70 and .64, respectively. The above results indicated that the CTS showed construct validity evidence and internal consistency reliability.

The third section of the SQ contained two open-ended Scientific Inquiry Competency Test (SICT) items. These items, 1) "Please design an experiment to collect data in order to make creative and innovative bicycle" (for primary school students), and 2) "Please design an experiment to collect data in order to compare what kinds of clothes can make better sun-protection baseball clothing" (for secondary school students), were designed to assess students' scientific inquiry competency. The content validity ratio (CVR) of the SICT was computed to assess the essentiality of items. The CVR values of two open-ended SICT items were .99 indicating a high degree of content validity. Furthermore, we coded the students' data by following PISA's 2015 scientific literacy framework (OECD, 2017). The coding indicators were used to assess students' scientific inquiry competency (Table 1). Therefore, a higher scientific inquiry competency coding score indicated better scientific inquiry competency. Two trained raters independently carried out the coding. Spearman's rank-order correlation coefficient (r_{sp}) was computed between the sets of coding and resulted in values ranging from .86 to .95, indicating a high degree of inter-rater reliability.

Table 1*The Indicators and Coding of Students' Levels of Scientific Inquiry Competency*

Competency	Indicator
1. Scientific phenomena explanation	1.1 Recall and apply appropriate scientific knowledge.
	1.2 Make and justify appropriate predictions.
	1.3 Offer explanatory hypotheses.
2. Scientific inquiry evaluation and design	1.1 Identify the question explored in a given scientific study.
	1.2 Distinguish questions that are possible to investigate scientifically.
	1.3 Propose a way of exploring a given question scientifically.
	1.4 Describe and evaluate a range of ways that scientists use to ensure the reliability of data and the objectivity and generalizability of explanations.
3. Scientific data and evidences interpretation	1.5 Analyze and interpret data and draw appropriate conclusions.
	1.6 Distinguish between arguments which are based on scientific evidence and theory and those based on other considerations.
	1.7 Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals)

Notes. Coding scores for each response ranged from 0 to 3, with "0" representing an irrelevant argument or no answer provided; "1" indicating a low level with simple or unclear argument; "2" reflecting a moderate level with reasonable and partially-complete argument; and "3" representing a high level with clear and complete components of argument.

Interview Protocols

Semi-structured interview protocols were developed to elicit additional information from the target students. These respondents were individually interviewed by the first researcher for 30-40 minutes in school meeting rooms.

A sample interview question was: 'Can you describe any change of your perceptions on critical thinking ability



and scientific inquiry competency while joining CDI intervention for me?' 'Please give me some examples to describe any differences in your science learning while participating in the CDI course.' All interviews were audiotaped and transcribed into searchable text files.

Treatment and Procedures

The EG students participated in a 20-week (40-hour) CDI intervention (two hours per week) over the course of two semesters, while the CG students participated in their regular science lessons within their classrooms. For the EG students, a typical CDI provided the following inquiry activities and time allotments: 1) The instructor introduced the background knowledge and information pertaining to a focus topic (15 minutes); 2) the instructor illustrated group task and helped students to work out the research hypothesis (5 minutes); 3) each group discussed their experimental design and completed the initial proposal (10 minutes); 4) each group presented their proposal and students were encouraged to engage in debate about controversial issues, provide their critical claims and evaluate conflicting evidence (25 minutes); 5) each group modified the proposal based on the peer and teacher's suggestions (5 minutes); 6) students worked together to conduct a hands-on activity and group game competition, followed by discussion within group, summarized consensus, identification of critical arguments, and drawing conclusions based on evidences to complete their worksheet (35 minutes); 7) each group took turns reporting their conclusions while others gave critical feedback and arguments about the presentations (20 minutes); and 8) the instructor made brief conclusions (5 minutes). For the CG students, the regular science lessons were teacher-centered which meant that science textbooks and lectures were the prime tools used to teach science knowledge.

In the EGs, each group consisted of 5-6 students, where students' group membership assignment was based on their science inquiry competency performance on the pretest, and groups were formed so that each group included high-, medium-, and low-ability students. All students were requested to participate in each of the CDI activities, cooperatively design group experiments, complete group worksheets, analyze research reports, present reasons and results in front of the whole class, and accept critique publicly during the intervention. Each activity covered a specific topic, with students in the primary and secondary school each covering ten topics (five topics each semester). In the primary school, the five first-semester CDI topics were "magic pen," "parachute competition," "creative paper flower," "tower competition," and "rocket balloon transformation," while the five second-semester CDI topics were "bubble dance," "wind power," "air cannon," "floating jellyfish," and "homemade acid and alkali indicator." In the secondary school, the five first-semester topics were "boomerang," "bouncing board," "ping pong spinning top," "elastic ball," "white paper tower," while the five second-semester CDI topics were "sound snake," "balance bird," "marshmallow challenge," "straw bird flute," and "pendulum experiment."

Data Analysis

SPSS Statistics 24.0 was used to analyze the quantitative data. Results from principal components analysis (PCA) and computed internal consistency coefficients were examined to assess construct validity and reliability evidence for the instrument. Then, students' responses to all instruments were analyzed using analyses of covariance (ANCOVAs), where 1) post-test 1 outcomes were compared between EG and CG groups using pretest scores as the covariate, 2) post-test 2 outcomes were compared using post-test 1 scores as the covariate, and 3) post-test 2 outcomes were compared using pretest scores as the covariate. Additionally, mixed-design analysis of variance (ANOVA) was used to assess group differences in CTS and SICT scores over the three time points. Finally, we used content theme analysis (Patton, 2002) to analyze the weekly observation and 2-wave interview results.

Research Results

The Effects of CDI Intervention on Students' Critical Thinking and Scientific Inquiry Competency

Appendix 1 shows the results of ANCOVAs to compare differences between EG and CG students' critical thinking and scientific inquiry scores in both primary school and secondary school. As these results show, among primary school students, and when controlling for first-semester pretest scores, the EG1 students' semester 2 post-test scores were significantly higher than their CG1 counterparts for analytical skills, problem-oriented thinking, truth-seeking, and CTS total scores. The open-mindedness scores of EG1 students were significantly higher than



CG1 students only at the end the second semester (i.e., post-test 2). For self-confidence, there were no statistically significant differences between the two primary school groups. When comparing the scientific inquiry competency scores for the two groups of primary school children (EG1 vs. CG1), and when controlling for first-semester pretest scores, we found that EG1 children's scientific inquiry evaluation and design, and scientific data and evidences interpretation, as well as on the SICT total scores were significantly higher than the scores of the CG1 children at each of the time points across the two semesters.

Appendix 2 shows results from ANCOVA models comparing the two groups of secondary school students (EG2 vs. CG2). These results showed that, when controlling for semester 1 pretest scores, students in the experimental group (EG2) showed significantly higher semester 2 posttest scores than their CG2 counterparts on analytical skills, problem-oriented thinking, open-mindedness, self-confidence, and truth-seeking, as well as on the CTS total score. The semester 2 post-test scores for scientific inquiry competency show that, when controlling for semester 1 pre-test scores, the EG2 students significantly outperformed the CG2 students in scientific inquiry evaluation and design and scientific data and evidence interpretation. For t scientific inquiry competency total scores, the EG2 students presented significantly higher scores than the CG2 students at the end of the first semester when controlling for semester 1 pretest scores, and at semester 2 posttest when controlling for semester 1 posttest scores.

The Primary and Secondary Students' Critical Thinking and Scientific Inquiry Competency Change across the 2-Semester Research Period

The results in Table 2 pertaining to primary school students show that the growth in EG children's analytical skills, problem-oriented thinking, open-mindedness, truth-seeking and CTS total was significantly greater than the growth of CG children. However, there was no significant difference between EG and CG children's scientific inquiry competency across the 2-semester research period.

When the data from secondary school students were considered, results (Table 3) showed that EG students showed significantly greater growth of the 2-semester period than their CG counterparts in CTS total scores, as well as in analytical skills, problem-oriented thinking, open-mindedness, self-confidence, and truth-seeking. Additionally, high school EG students also showed significantly greater growth than CG students in SICT total scores and scientific inquiry evaluation and design.

Table 2

Results of Mixed-design ANOVAs Comparing Experimental Group and Control Group Growth in Critical Thinking and Scientific Inquiry Competency among Primary School Students

Dimensions	Group	The 1 st semester pretest M (SD)	The 1 st semester posttest M (SD)	The 2 nd semester posttest M (SD)	F	p	η^2
Analytical skills	EG1	21.32 (3.50)	23.16 (2.90)	24.20(2.35)	22.56***	< .001	.20
	CG1	21.36 (4.50)	20.36 (4.81)	19.68 (4.23)			
Problem-oriented thinking	EG1	12.60 (2.94)	14.48 (2.29)	15.88 (1.94)	28.48***	< .001	.08
	CG1	11.64 (2.77)	13.64 (3.75)	13.04(3.21)			
Open-mindedness	EG1	18.32 (2.85)	20.96 (2.65)	21.52 (2.29)	9.53***	< .001	.04
	CG1	18.96 (2.47)	20.36 (4.38)	20.36 (4.38)			
Self-confidence	EG1	10.56 (2.27)	11.72 (1.51)	12.08 (1.32)	2.11	.132	.03
	CG1	10.32 (2.09)	10.75 (2.96)	10.89 (2.94)			
Truth-seeking	EG1	6.52 (1.64)	8.40 (1.85)	9.00 (1.80)	13.51***	< .001	.25
	CG1	7.61 (1.87)	7.07 (2.05)	7.18 (1.81)			
CTS total	EG1	69.32 (7.54)	78.72 (7.30)	82.68 (6.41)	64.15***	< .001	.16
	CG1	69.89 (9.57)	72.18(14.94)	71.14(13.72)			



Dimensions	Group	The 1 st semester pretest M (SD)	The 1 st semester posttest M (SD)	The 2 nd semester posttest M (SD)	F	p	η ²
Scientific phenomena explanation	EG1	6.52 (1.19)	7.56 (1.08)	7.64 (1.15)	1.52	.228	.05
	CG1	6.75 (1.86)	6.86 (1.69)	6.93 (1.54)			
Scientific inquiry evaluation and design	EG1	9.92 (1.26)	10.60 (1.04)	10.92 (1.12)	1.95	.152	.04
	CG1	9.89 (1.75)	9.89(2.03)	10.11(1.62)			
Scientific data and evidences interpretation	EG1	6.36 (1.00)	7.32 (1.15)	7.88 (0.97)	1.03	.364	.02
	CG1	6.32 (1.57)	6.61 (1.66)	7.14 (1.43)			
SICT total	EG1	22.80 (1.66)	25.48 (2.43)	26.44 (2.14)	2.50	.092	.06
	CG1	22.96 (4.32)	23.36 (3.90)	24.18 (3.24)			

Notes. *** $p \leq .001$; small effect size of η^2 : 0.010; medium effect size of η^2 : 0.059; large effect size of η^2 : 0.138 (Cohen, 1988). Bold numbers indicate significant differences between groups.

Table 3
Results of Mixed-design ANOVAs Comparing Experimental Group and Control Group Growth in Critical Thinking and Scientific Inquiry Competency among Secondary School Students

Dimensions	Group	The 1 st semester pretest M (SD)	The 1 st semester posttest M (SD)	The 2 nd semester posttest M (SD)	F	p	η ²
Analytical skills	EG2	21.93 (2.81)	22.39 (2.82)	23.36(2.28)	3.60*	.034	.04
	CG2	19.60 (3.87)	19.27 (3.62)	19.83 (3.53)			
Problem-oriented thinking	EG2	13.29 (3.13)	14.39 (2.86)	15.54 (2.00)	10.98***	< .001	.14
	CG2	11.47 (3.44)	11.27 (3.30)	11.53(3.55)			
Open-mindedness	EG2	22.21 (2.46)	23.11 (2.13)	23.93 (1.80)	8.65***	.001	.09
	CG2	20.93 (2.46)	21.17 (2.38)	21.07 (2.41)			
Self-confidence	EG2	10.71 (1.74)	11.46 (1.35)	12.57 (1.67)	8.53***	.001	.15
	CG2	10.77 (2.00)	10.77 (1.99)	10.90 (2.01)			
Truth-seeking	EG2	8.25 (1.62)	8.68 (1.66)	9.64 (1.31)	4.77*	.012	.07
	CG2	7.80 (1.94)	8.13 (1.78)	8.20 (1.85)			
CTS total	EG2	76.39 (7.96)	80.00 (7.18)	85.04 (6.00)	22.54***	< .001	.17
	CG2	70.57 (9.92)	70.60 (9.39)	71.53 (9.72)			
Scientific phenomena explanation	EG2	7.43 (1.03)	7.29 (1.15)	7.71 (1.18)	1.13	.331	.02
	CG2	6.77 (1.38)	7.03 (1.43)	7.30 (1.02)			
Scientific inquiry evaluation and design	EG2	9.43 (1.00)	9.93 (0.94)	10.46 (0.92)	3.69*	.031	.03
	CG2	9.10 (1.45)	10.20 (1.13)	10.17 (1.29)			
Scientific data and evidences interpretation	EG2	8.04 (0.88)	8.07 (0.98)	8.39 (0.83)	2.02	.142	.02
	CG2	7.47 (1.55)	7.93 (1.29)	7.97 (1.27)			
SICT total	EG2	24.89 (1.64)	25.29 (1.82)	26.57 (1.71)	5.49**	.007	.05
	CG2	23.33 (3.25)	25.17 (2.89)	25.43 (2.84)			

Notes. * $p < .05$; ** $p < .01$; *** $p \leq .001$; small effect size of η^2 : 0.010; medium effect size of η^2 : 0.059; large effect size of η^2 : 0.138 (Cohen, 1988). Bold numbers indicate significant differences between groups.



The Impact of CDI Intervention on Primary and Secondary School Students' Critical Thinking and Scientific Inquiry Competency

The interview data from target students next were examined to explore how the CDI intervention impacted both primary and secondary school target students' critical thinking and scientific inquiry competency. The following four themes emerged from the interviews.

Theme 1: Group Game Competition and Critique-Driven Topic Discussion Served as a Catalyst for Improving Primary School Students' Critical Thinking

From the results based on the target students' interviews, we found that an interesting and competitive group game not only can improve low-CTS primary school students' ability to think critically, but also can boost their learning interest and motivation.

Wang (a low-CTS 4th grade girl) said:

I always look forward to trying different and interesting scientific games and completing the task with my teammates which helps me gain more confidence in science learning.

Chang (a low-CTS 4th grade boy) said:

After I participate in CDI science course, I have lots of fun from group game competition and learn more scientific knowledge from problem thinking and peer discussion.

Conversely, for high-CTS primary school students, critical and contextualized scientific-topic discussion is more helpful for than group game competition to develop analytical skills and critical thinking.

Lee (a high-CTS 4th grade girl) said:

It is very challenging for me to think critical scientific-topic issues at the 1st semester. However, I found my ability of analytical skills become more progressive after one semester CDI intervention. Now, I have much more self-confidence on science learning.

Liu (a high-CTS 4th grade boy) said:

I am very interested in the CDI course especially the interesting scientific-topic discussion and hands-on tasks. Teacher always guides us to reflect and discuss lots of close-to-life scientific issues to train our ability of critical thinking.

Theme 2: Whole Group Discussion and Counter-Critique Argumentation Can Advance Secondary School Students' Critical Thinking

Based on the interview data, we found that weekly scientific topic group discussion is an effective way to enhance low-CTS secondary students' analytical skills and critical thinking.

Lin (a low-CTS 7th grade girl) said:

I had very low self-confidence in learning science and always kept away from any science activities previously. After I participate in CDI, I learn how to analyze scientific phenomena from peer group discussion and have fun from teamwork.

Huang (a low-CTS 7th grade boy) said: I do not have good performance on science test, so I am scared of learning science. However, CDI teachers and my teammates always encourage and guide me to propose ideas while group discussion. Now, I have more confidence on my problem thinking.

In addition, high-CTS secondary students can develop open-minded attitudes and critical thinking performance through critical idea reflections and counter-critique argumentations.

Hsiao (a high-CTS 7th grade girl) said:

I always look forward to weekly whole group oral presentation and counter-critique, because I can acquire lots of scientific knowledge inspiration and share ideas with teachers and classmates which makes me more actively involved in science learning.



Yang (a high-CTS 7th grade boy) said:

I am not used to listening to others opinion before. After joining CDI class, I become more open-minded to accept others' ideas and reflect others' argumentations.

Theme 3: Interesting Video Appreciation and Hands-on Activities Would Increase Primary School Students' Scientific Inquiry Competency

In this research, we integrated interesting video materials and creative hands-on experiments into every CDI Unit course. This not only can enhance low-SICT children's engagement but also strengthen high-SICT children's scientific inquiry competency.

Hsu (a low-SICT 4th grade girl) said:

I am very excited to watch scientific video during the CDI class, because I can gain more scientific knowledge and explore interesting scientific phenomena through interesting video appreciation.

Chen (a low-SICT 4th grade boy) said:

I had very low self-confidence in science learning previously. I face lots of difficulties to design experiments and explain research results at first semester. However, CDI teachers and teammates always encouraged me to try different hands-on activities and helped me solve problems. Now, I enjoy doing experiments and have more confidence to find evidences on scientific phenomena.

Hong (a high-SICT 4th grade girl) said:

I like to design and try different hands-on experiments. After I join the CDI class, I have more opportunities to find scientific theory and strengthen my scientific inquiry evaluation ability.

Chou (a high-SICT 4th grade boy) said:

I learn how to communicate and share ideas with teammates from video appreciation and hands-on activities discussion at CDI class. It offers a good way to build up my scientific inquiry competency.

Theme 4: Group Experimental Design and Oral Presentation Can Enhance Secondary School Students' Scientific Inquiry Competency

Based on target students' interview results, we found that weekly group experimental design activities, hands-on activities, and oral presentations can foster low-SICT secondary students' curiosity and scientific inquiry competency. It can also improve high-SICT secondary students' ability to interpret scientific data and evidence.

Ma (a low-SICT 7th grade girl) said:

It was difficult for me to do hands-on experiments at the 1st semester. But now I enjoy explaining scientific evidence and results interesting results from group counter-critique.

Yen (a low-SICT 7th grade boy) said:

At first semester, I had low interest in hands-on experiments. Now, I enjoy designing interest experiments, have more confidence to offer scientific argumentation and always serve as a volunteer to present our team's research results in front of the whole class.

Lu (a high-SICT 7th grade girl) said:

I engaged in experimental design, hands-on activities frequently and had better ability on interpreting scientific data and evidence from research results than before.

Hung (a high-SICT 7th grade boy) said:

My scientific competency was not good and rarely gave complete argumentation before, but my critical scientific inquiry has been enhanced a lot after joining CDI intervention. I was more active to find answer and evidence from different sources.



Based on the above interview results, the research found that competitive group game and counter-critique argumentation and discussion can improve students' critical thinking, while interesting hands-on activities, video demonstration, experimental design activities, and oral presentations can enhance students' curiosity and scientific inquiry competency.

Discussion

Previous studies have indicated that inquiry-driven teaching approaches can have effects on students' analytical skills, problem-solving, truth-seeking, and scientific inquiry competency (Lin et al., 2016; Marshall et al., 2017). The current research confirms these effects and identifies additional effects. Specifically, EG 7th graders in the research became more open-minded, strove to accomplish challenging tasks, reflected more, thought critically, and were willing to modify their personal viewpoint to enhance the quality of their conclusion. Results indicate that the CDI intervention positively impacts EG students' self-confidence and interest in learning science. In addition, compared to the CG 7th graders, the EG 7th graders showed more explicit engagements, developed different strategies to evaluate and design scientific inquiry, and became more skilled in scientific reasoning and in their ability to interpret at data and evidence, especially in the 2nd semester. By emphasizing critical thinking in the delivery of science inquiry instruction, enhanced effects were realized, which supports the assertions of Swartz and McGuinness (2014), who stated that more explicit teaching about critical thinking and reflections resulted in greater positive impact on students. This observation has implications for future studies that aim to examine student critical thinking and scientific inquiry competency. Specifically, the research affirms the importance of integrating cognitively demanding tasks like critique and reflection into inquiry-based learning activities.

The CTS growth pattern of EG primary school children was significantly and substantially greater than those who did not receive the CDI intervention. Based on interview data, we found that scientific video presentation, inquiry-based hands-on activities, and scientific competition can effectively improve primary school children's abilities to solve problems, interpret data, and explain scientific phenomena. The significantly greater progress made by EG 7th graders' SICT across the 2-semester intervention might relate to a hierarchical and systematic content design, because scientific inquiry evaluation and scientific evidences interpretation competency are competencies that require a high level cognitive level (Bloom, 1956; OECD, 2017) and students may require more time to explore their thinking skills for problem-solving. The practice of building cognitively-demanding thinking skills among students through inquiry-based teaching is integral to successful learning outcomes and recommended by previous studies (Tekkumru-Kisa et al., 2018; Yang et al., 2019), but these studies have not explored how students might engage effectively in critique and reflection. Our results suggest that integrating critique and reflection can provide a pathway that facilitates high levels of student thinking. Otherwise, when CDI is infused with the utilization of counter-critique argumentation, a cooperative learning with peers is suggested (Johnson & Johnson, 1994; Lee et al., 2013). The current research echoes the recommendations of Swartz and McGuinness (2014), who assert that combining activities that promote critical thinking strategies to an inquiry-oriented approach together with scaffolding guidance provided by the teacher can create a very powerful learning environment for reflective thinking. In addition, the current research found that a well-designed learning environment is conducive to the development of learners' scientific inquiry competency (Wong & Hodson, 2010).

The impact of inquiry-based teaching of science on students' learning motivation and engagement has been shown in prior research (Bernard & Dudek-Rózycki, 2020; Jiang & McComas, 2015). The empirical data from the present research confirm that the CDI teaching approach of integrating cognitive-demanding learning tasks such as critique and reflection are effective in promoting students' critical thinking and scientific inquiry competency. The qualitative results add new value to the existing literature, showing that the intervention components (group competition, discussion/argumentation, engaging video content, inquiry-based hands-on activities, group design experiments, and oral presentation) can be effective in enhancing critical thinking and scientific inquiry competency among both primary and secondary school students.

One of the noteworthy results of this research was that EG students (who received the CDI intervention) achieved higher scores on critical thinking and scientific inquiry competency than their CG counterparts. The second essential result was that the inquiry-based, hands-on activities and critique-oriented discussion provided fresh insight into CDI instruction for learners. Despite of the observed effects of the CDI intervention, it



is important to acknowledge that students' awareness of being observed can alter their behavior and threaten research integrity (Allen, 2015; Oluwatayo, 2012). Although students in this research were not made aware of their group membership (EG or CG) during the intervention, the CG students could conceivably have guessed the purpose of the research, which had the potential to produce the "John Henry effect," whereby those not receiving treatment strived to outperform their peers who did receive the treatment (Adair, 1984). This, however, seems unlikely, given that the experimental group consistently outperformed the control group. However, it's possible that a Hawthorne effect could have interfered with the validity of the research because of the increased attention and expectations given to EG students' during the intervention (McCarney et al., 2007). Therefore, we suggest that future studies might consider implementing a longitudinal design to assess the effects of CDI through participants' long-term learning outcomes.

Conclusions and Implications

This research not only sheds light on how a CDI curricular design that integrates critical and reflective competencies into a structured approach of scientific inquiry teaching practices can effectively be implemented, it also provides empirical evidence using both quantitative data and qualitative data that supports the effectiveness of such practices on learning outcomes and scientific competencies that are emphasized by NRC (2000). The current research integrated critical thinking into inquiry-based instruction for two semesters, and the resulting evidence suggests that this promoted both primary and secondary school students' critical thinking and scientific inquiry competencies. It suggests that future studies expand on this to explore how such an approach might be incorporated into the professional development of teachers, coupled with an assessment of the effectiveness of such professional development efforts on student learning outcomes. Furthermore, a longitudinal research design—conducted, for example, from 4th to 7th grade—would provide even more informative data to observe intra-individual changes and developments in students' critical thinking ability (analytical skills, problem-oriented thinking, open-mindedness, self-confidence, truth-seeking) and scientific inquiry competencies (scientific phenomena explanation, scientific inquiry evaluation and design, scientific data and evidences interpretation) across the essential transition students make from primary school children to secondary school adolescents. It is hoped that the identification of effective CDI teaching strategies opens a window to allow future studies to develop and extend ways of promoting students' critical thinking and scientific inquiry competencies.

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Appendix 1

ANCOVA results for comparison of EG and CG primary school students' critical thinking and scientific inquiry competency across two semesters

Dimensions	Semesters	Groups	N	Mean of pretest	SD	Mean of posttest	SD	Adjusted posttest mean	Adjusted posttest SE	F	p	η^2
Analytical skills	1 st semester	EG1	25	21.32	3.50	23.16	2.90	23.17	0.69	8.79**	.005	.11
		CG1	28	21.36	4.50	20.36	4.81	20.35	0.65			
	2 nd semester	EG1	25	23.16	2.90	24.20	2.35	22.96	0.17	81.46***	< .001	.06
		CG1	28	20.36	4.81	19.68	4.23	20.79	0.16			
	two semesters	EG1	25	21.32	3.50	24.20	2.35	24.21	0.63	27.60***	< .001	.31
		CG1	28	21.36	4.50	19.68	4.23	19.67	0.59			
Problem-oriented thinking	1 st semester	EG1	25	12.60	2.94	14.48	2.29	14.13	0.50	0.06	.807	.00
		CG1	28	11.64	2.77	13.64	3.75	13.96	0.47			
	2 nd semester	EG1	25	14.48	2.29	15.88	1.94	15.52	0.16	95.64**	< .001	.13
		CG1	28	13.64	3.75	13.04	3.21	13.36	0.15			
	two semesters	EG1	25	12.60	2.94	15.88	1.94	15.61	0.45	14.02***	< .001	.15
		CG1	28	11.64	2.77	13.04	3.21	13.28	0.42			



Open-mindedness	1 st semester	EG1	25	18.32	2.85	20.96	2.65	21.18	0.66	1.26	.266	.02
		CG1	28	18.96	2.47	20.36	4.38	20.16	0.62			
	2 nd semester	EG1	25	20.96	2.65	21.52	2.29	21.21	0.09	20.22***	< .001	.01
		CG1	28	20.36	4.38	20.36	4.38	20.63	0.09			
	two semesters	EG1	25	18.32	2.85	21.52	2.29	21.72	0.65	2.92	.094	.05
		CG1	28	18.96	2.47	20.36	4.38	20.18	0.61			
Self-confidence	1 st semester	EG1	25	10.56	2.27	11.72	1.51	11.65	0.42	2.10	.153	.03
		CG1	28	10.32	2.09	10.75	2.96	10.81	0.40			
	2 nd semester	EG1	25	11.72	1.51	12.08	1.32	11.60	0.10	3.69	.060	.00
		CG1	28	10.75	2.96	10.89	2.94	11.33	0.10			
	two semesters	EG1	25	10.56	2.27	12.08	1.32	12.02	0.41	3.54	.066	.05
		CG1	28	10.32	2.09	10.89	2.94	10.95	0.39			
Truth-seeking	1 st semester	EG1	25	6.52	1.64	8.40	1.85	8.61	0.39	10.07**	.003	.16
		CG1	28	7.61	1.87	7.07	2.05	6.89	0.36			
	2 nd semester	EG1	25	8.40	1.85	9.00	1.80	8.39	0.13	13.85***	.001	.03
		CG1	28	7.07	2.05	7.18	1.81	7.72	0.12			
	two semesters	EG1	25	6.52	1.64	9.00	1.80	9.15	0.36	17.24***	< .001	.25
		CG1	28	7.61	1.87	7.18	1.81	7.04	0.34			
CTS total	1 st semester	EG1	25	69.32	7.54	78.72	7.30	78.94	2.05	6.11*	.017	.08
		CG1	28	69.89	9.57	72.18	14.94	71.98	1.93			
	2 nd semester	EG1	25	78.72	7.30	82.68	6.41	79.56	0.30	182.20***	< .001	.05
		CG1	28	72.18	14.94	71.14	13.72	73.93	0.28			
	two semesters	EG1	25	69.32	7.54	82.68	6.41	82.87	1.91	20.55***	< .001	.24
		CG1	28	69.89	9.57	71.14	13.72	70.97	1.80			
Scientific phenomena explanation	1 st semester	EG1	25	6.52	1.19	7.56	1.08	7.58	0.29	3.49	.068	.06
		CG1	28	6.75	1.86	6.86	1.69	6.84	0.27			
	2 nd semester	EG1	25	7.56	1.08	7.64	1.15	7.37	0.18	0.61	.439	.00
		CG1	28	6.86	1.69	6.93	1.54	7.17	0.17			
	two semesters	EG1	25	6.52	1.19	7.64	1.15	7.65	0.28	3.58	.064	.07
		CG1	28	6.75	1.86	6.93	1.54	6.92	0.26			
Scientific inquiry evaluation and design	1 st semester	EG1	25	9.92	1.26	10.60	1.04	10.60	0.32	2.57	.115	.05
		CG1	28	9.89	1.75	9.89	2.03	9.90	0.30			
	2 nd semester	EG1	25	10.60	1.04	10.92	1.12	10.63	0.13	2.27	.139	.01
		CG1	28	9.89	2.03	10.11	1.62	10.36	0.12			
	two semesters	EG1	25	9.92	1.26	10.92	1.12	10.92	0.26	5.09*	.028	.08
		CG1	28	9.89	1.75	10.11	1.62	10.11	0.24			

Scientific data and evidences interpretation	1 st semester	EG1	25	6.36	1.00	7.32	1.15	7.32	0.29	3.16	.081	.06
		CG1	28	6.32	1.57	6.61	1.66	6.61	0.27			
	2 nd semester	EG1	25	7.32	1.15	7.88	0.97	7.66	0.19	1.52	.224	.01
		CG1	28	6.61	1.66	7.14	1.43	7.34	0.17			
	two semesters	EG1	25	6.36	1.00	7.88	0.97	7.88	0.25	4.59*	.037	.08
		CG1	28	6.32	1.57	7.14	1.43	7.14	0.24			
SICT total	1 st semester	EG1	25	22.80	1.66	25.48	2.43	25.50	0.65	5.84*	.019	.10
		CG1	28	22.96	4.32	23.36	3.90	23.34	0.61			
	2 nd semester	EG1	25	25.48	2.43	26.44	2.14	25.58	0.24	3.43	.070	.01
		CG1	28	23.36	3.90	24.18	3.24	24.95	0.23			
	two semesters	EG1	25	22.80	1.66	26.44	2.14	26.45	0.55	9.05**	.004	.15
		CG1	28	22.96	4.32	24.18	3.24	24.17	0.55			

Notes. * $p < .05$; ** $p < .01$; *** $p \leq .001$; small effect size of η^2 : 0.010; medium effect size of η^2 : 0.059; large effect size of η^2 : 0.138 (Cohen, 1988). Bold numbers indicate significant differences between groups.

Appendix 2

ANCOVA results for comparison of EG and CG secondary school students' critical thinking and scientific inquiry competency across two semesters

Dimensions	Semesters	Groups	N	Mean of pretest	SD	Mean of posttest	SD	Adjusted posttest mean	Adjusted posttest SE	F	p	η^2
Analytical skills	1 st semester	EG2	28	21.93	2.81	22.36	2.82	21.49	0.42	5.51*	.022	.03
		CG2	30	19.60	3.87	19.27	3.62	20.08	0.41			
	2 nd semester	EG2	28	22.36	2.82	23.36	2.28	21.96	0.19	9.07**	.004	.01
		CG2	30	19.27	3.62	19.83	3.53	21.14	0.18			
	two semesters	EG2	28	21.93	2.81	23.36	2.28	22.52	0.36	13.68***	.001	.07
		CG2	30	19.60	3.87	19.83	3.53	20.62	0.35			
Problem-oriented thinking	1 st semester	EG2	28	13.29	3.13	14.39	2.86	13.69	0.37	11.59***	.001	.06
		CG2	30	12.34	3.39	11.27	3.30	11.92	0.36			
	2 nd semester	EG2	28	14.39	2.86	15.54	1.99	14.20	0.28	12.10***	.001	.03
		CG2	30	11.27	3.30	11.53	3.55	12.79	0.27			
	two semesters	EG2	28	13.29	3.13	15.54	1.99	14.84	0.31	36.31***	< .001	.14
		CG2	30	12.34	3.39	11.53	3.55	12.18	0.30			
Open-mindedness	1 st semester	EG2	28	22.21	2.46	23.11	2.13	22.73	0.34	6.17*	.016	.06
		CG2	30	20.93	2.46	21.17	2.38	21.52	0.33			
	2 nd semester	EG2	28	23.11	2.13	23.93	1.80	23.13	0.23	15.80***	< .001	.06
		CG2	30	21.17	2.38	21.07	2.41	21.81	0.22			
	two semesters	EG2	28	22.21	2.46	23.93	1.80	23.52	0.29	24.98***	< .001	.16
		CG2	30	20.93	2.46	21.07	2.41	21.45	0.28			



Dimensions	Semesters	Groups	N	Mean of pretest	SD	Mean of posttest	SD	Adjusted posttest mean	Adjusted posttest SE	F	p	η^2						
Self-confidence	1 st semester	EG2	28	10.71	1.74	11.46	1.35	11.48	0.23	5.44*	.023	.05						
		CG2	30	10.77	2.00	10.77	2.00	10.75	0.22									
	2 nd semester	EG2	28	11.46	1.35	12.57	1.67	12.26	0.22				16.03***	< .001	.09			
		CG2	30	10.77	2.00	10.77	2.00	11.06	0.21									
	two semesters	EG2	28	10.71	1.74	12.57	1.67	12.59	0.30							19.44***	< .001	.20
		CG2	30	10.77	2.00	10.77	2.00	10.75	0.30									
Truth-seeking	1 st semester	EG2	28	8.25	1.62	8.68	1.66	8.51	0.21	0.53	.470	.00						
		CG2	30	7.80	1.94	8.13	1.78	8.29	0.21									
	2 nd semester	EG2	28	8.68	1.66	9.64	1.31	9.46	0.22				12.41***	.001	.09			
		CG2	30	8.13	1.78	8.20	1.85	8.37	0.21									
	two semesters	EG2	28	8.25	1.62	9.64	1.31	9.50	0.22							14.33***	< .001	.11
		CG2	30	7.80	1.94	8.20	1.85	8.34	0.21									
CTS total	1 st semester	EG2	28	76.39	7.96	80.00	7.18	77.92	1.10	11.74***	.001	.07						
		CG2	30	70.57	9.92	70.60	9.39	72.54	1.06									
	2 nd semester	EG2	28	80.00	7.18	85.04	6.00	80.70	0.68				27.08***	< .001	.05			
		CG2	30	70.60	9.39	71.40	9.78	75.44	0.66									
	two semesters	EG2	28	76.39	7.96	85.04	6.00	82.87	0.98							46.18***	< .001	.18
		CG2	30	70.57	9.92	71.40	9.78	73.42	0.94									
Scientific phenomena explanation	1 st semester	EG2	28	7.43	1.03	7.29	1.15	7.04	0.19	0.67	.416	.01						
		CG2	30	6.77	1.38	7.03	1.43	7.26	0.18									
	2 nd semester	EG2	28	7.29	1.15	7.71	1.18	7.65	0.17				1.50	.226	.02			
		CG2	30	7.03	1.43	7.30	1.02	7.36	0.16									
	two semesters	EG2	28	7.43	1.03	7.71	1.18	7.56	0.19							0.21	.652	.00
		CG2	30	6.77	1.38	7.30	1.02	7.44	0.18									
Scientific inquiry evaluation and design	1 st semester	EG2	28	9.43	1.00	9.93	0.94	9.86	0.17	2.85	.097	.04						
		CG2	30	9.10	1.45	10.20	1.13	10.27	0.18									
	2 nd semester	EG2	28	9.93	0.94	10.46	0.92	10.57	0.15				5.79*	.019	.05			
		CG2	30	10.20	1.13	10.17	1.29	10.07	0.15									
	two semesters	EG2	28	9.43	1.00	10.46	0.92	10.37	0.17							0.23	.632	.00
		CG2	30	9.10	1.45	10.17	1.29	10.26	0.16									
Scientific data and evidences interpretation	1 st semester	EG2	28	8.04	0.88	8.07	.98	7.95	0.20	0.15	.700	.00						
		CG2	30	7.47	1.55	7.93	1.29	8.05	0.19									
	2 nd semester	EG2	28	8.07	0.98	8.39	0.83	8.34	0.10				4.71*	.034	.02			
		CG2	30	7.93	1.29	7.97	1.27	8.02	0.10									
	two semesters	EG2	28	8.04	0.88	8.39	0.83	8.27	0.18							0.53	.469	.01
		CG2	30	7.47	1.55	7.97	1.27	8.08	0.18									

Dimensions	Semesters	Groups	N	Mean of pretest	SD	Mean of posttest	SD	Adjusted posttest mean	Adjusted posttest SE	F	p	η^2
SICT total	1 st semester	EG2	28	24.89	1.64	25.29	1.82	24.72	0.31	4.87*	.032	.04
		CG2	30	23.33	3.25	25.17	2.89	25.70	0.30			
	2 nd semester	EG2	28	25.29	1.82	26.57	1.71	26.53	0.28	7.17**	.010	.05
		CG2	30	25.17	2.89	25.43	2.84	25.48	0.27			
	two semesters	EG2	28	24.89	1.64	26.57	1.71	26.04	0.32	0.06	.816	.00
		CG2	30	23.33	3.25	25.43	2.84	25.93	0.30			

Notes: * $p < .05$; ** $p < .01$; *** $p \leq .001$; small effect size of η^2 : 0.010; medium effect size of η^2 : 0.059; large effect size of η^2 : 0.138 (Cohen, 1988). Bold numbers indicate significant differences between groups.

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