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Longitudinal study of a cooperation-driven, socio-scientific issue intervention on promoting students' critical thinking and self-regulation in learning science

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ABSTRACT
This longitudinal study explored the effects of a Cooperation-driven Socioscientific Issue (CDSSI) intervention on junior high school students' perceptions of critical thinking (CT) and self-regulation (SR) in Taiwan. Forty-nine grade 7 students were randomly selected as an experimental group (EG) to attend a 3-semester 72-hour intervention; while another 49 grade 7 students from the same school were randomly selected as the comparison group (CG). All participants completed a 4-wave student questionnaire to assess their perceptions of CT and SR. In addition, 8 target students from the EG with the lowest scores on either CT or SR were purposefully recruited for weekly observation. These target students and their teachers were interviewed one month after the intervention in each semester. Analyses of covariance and paired-wise *t*-tests revealed that the EG students' perceptions of CT and SR in learning science were improved during the study and were significantly better than their counterparts' at the end of the study. Systematic interview and classroom observation results were consistent with the quantitative findings. This study adds empirical evidence and provides insights into how CDSSI can be integrated into planning and implementing effective pedagogical strategies aimed at increasing students' perceptions of CT and SR in learning science.

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Cooperation-driven SSI; critical thinking; longitudinal study; self-regulation; students' perceptions; Taiwan

Introduction

In an information-rich and knowledge-oriented society, promoting students' critical thinking (CT) skills and self-regulated (SR) learning have been identified as a key goal of science education (Jenkins, 2011; National Research Council, 2007; OECD, 2001). It is believed that CT is the heart of one's capacity to evaluate problem-solving procedures, justify arguments and make-educated decisions (Yang & Chung, 2009). In addition, SR is a process of taking control and evaluating one's own learning and behaviour which emphasises autonomy and control of the individual, who monitors, directs and regulates actions towards goals (Ormrod (2009).

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Student interest in and attitudes towards science start to decline when the student transitions from elementary to secondary school (Larkin & Jorgensen, 2016). This decline might be related to decreased self-efficacy and self-confidence and failure to promote students' understanding about how school science learning contributes to their personal life (Hong, 2010; Hong & Lin, 2011; Hong, Lin, & Larenz, 2012; Hong, Lin, Wang, Chen, & Yang, 2013; Hong, Lin, Chen, Wang, & Lin, 2014; Barber & Olsen, 2004; Gilbert, Bulte, & Pilot, 2011; Jenkins, 2011; NRC, 2007). Contemporary psychology research draws attention to the importance of developing students' self-believed and self-regulatory capacities (Zimmerman, 2008). One of the goals of science education is to motivate and empower students by nurturing the belief that they can succeed in science learning and cultivating the self-regulatory strategies that are required bringing them success (Velayutham & Aldridge, 2013). In addition, Paul (1995) advocated comprehensive conception as a necessary CT tool for bringing about readiness to meet the impending challenges.

Increasing students' life-long learning is much more important than only focusing on students' academic achievement (Ainley & Ainley, 2011; Hong et al., 2014). Day and Bryce (2013) recommended that a curricular strand called 'Topical Science' should be used to embed socio-scientific discussions in the science education curriculum socio-scientific issue (SSI) are complex and controversial containing open-ended and potentially contentious problems which lack a single or straightforward solution. Therefore, students are encouraged to engage in debating controversial science-related social issues, evaluating conflicting evidence, identifying critical data, reflecting on different opinions, defending their own position and making evidence-based decisions (Bodmer, 1985). In addition, cooperative learning (CL) is widely recognised as a teaching strategy that promotes learning and socialisation across different subject domains, such as reading, writing, understanding and conceptual development in science classes, problem-solving in math and high-order thinking (Gillies, 2014; Johnson & Johnson, 2003). Thus, CL experiences are crucial to preventing and alleviating many of the social problems related to children, adolescents and young adults (Gillies, 2014).

Typical Taiwanese students are influenced by Confucian heritage culture (CHC), which encourages students to maintain harmony and avoid conflicts in front of others which could be an obstacle to the development of students' CT skills. In addition, many studies found that Taiwanese students view themselves as children following instructors' (e.g. parents' and teachers') directions (i.e. Hong, McCarthy Veach, & Lawrenz, 2004; Chiu, 2009). Because of these perceptions how to improve students' SR and CT is an important goal in current education in Taiwan. The purpose of this study was to investigate the effects of an intervention using cooperation-driven SSI (CDSSI) on enhancing students' CT and SR in learning science.

Literature review

Reviews of studies on adolescents' perceived CT (Goodlad, 1984), SR (Zimmerman, 2001) and CL (Johnson & Johnson, 2003) provided the background for planning and conducting this CDSSI intervention (Sadler, 2004). We limited this literature review to the Taiwan cultural context over the past two decades.

Asian students' CT

Over the past two decades there have been many studies that emphasise the importance of CT (e.g. Case & Wright, 1997; Chiu, 2009; Ennis, 1996; Goodlad, 1984; Watkins & Biggs, 2001; Yang & Chung, 2009). For example, Goodlad (1984) found that adolescents who failed to engage in critical and higher-order thinking might not be well prepared for future society and globalisation; that CT was crucial to nurturing a democratic citizenry. Moreover, Chiu (2009) found that students from a Chinese cultural background do not perform well in verbalised CT. In a cultural comparison study, Tiwari, Avery, and Lai (2003) found that Hong Kong students have negative dispositions towards CT compared with Australian University students. Nevertheless, Asian graduates educated within the CHC are generally found to reach higher achievement levels than those who are educated with Western approaches (Watkins & Biggs, 2001). However, students who have been enculturated in CHC have learned to value diligent study, social harmony, respect for teachers' authority and avoidance of conflict in face-to-face classroom environments (Chang, 2001; Sun, 2003; Williams, Watkins, Daly, & Courtney, 2001). Chiu's (2009) study found that probing and open student–student and teacher–student interaction are not used by Taiwanese students, nor is public questioning or challenging of authority typical in Taiwan classroom settings.

While constructivists generally agreed that CT is socially constructed and developed collaboratively through students' language-mediated social interactions with peers and teachers, Jonassen (2001), Littlejohn (1996) and Vygotsky (1978) have confirmed that social constructivism can also be accomplished through online interactions and used for the development of CT. In addition, Lee et al. (2013) observed and confirmed that encouraging in depth learning can lead to improvement of CT. Paul (1995) stated that CT is a unique and purposeful form of thinking which entails analysing, evaluating, explaining and restructuring one's own thinking. Erwing (2000) furthermore defined CT as (1) clarifying the problem of the issue considered; (2) identifying the background knowledge offered to support any declared claim; (3) recognising unstated assumptions in a statement; (4) distinguishing facts from opinions and inference; (5) checking the credibility and validity of the evidence; (6) comparing and contrasting the stances of different sources of information and (7) reaching a conclusion among diverse sources of information through logical reasoning. In addition, Chiu (2009) added one more criterion of CT: showing cognitive flexibility and full consideration of affective and cultural factors involved in an issue. We hypothesised that applying a Western communication pedagogy – the CDSSI intervention – in the full CHC country of Taiwan which produces less emphasis on CT has the potential to promote students' CT.

How does SR benefit adolescents' science learning?

Zimmerman (2001) indicated that individuals' thoughts, affects and behaviours used to attain learning goals are the essential elements of SR. Similar views from Eccles and Wigfield (2002) defined SR learning as being meta-cognitively, motivationally and behaviourally active in one's own learning process. Pintrich (2000) also believed that an SR learning perspective includes cognitive, motivational, affective and contextual factors. Furthermore, Zimmerman (2002) asserted that successful learners organise their work, set goals, seek help when needed, use effective work strategies, and manage their time. Overall, learning should be viewed as an activity that students do for themselves, in a proactive way, rather than as passive learners accepting instructors' perspectives during learning process.

Researchers have increasingly emphasised the importance of SR on students' learning outcomes (Pintrich, Wolters, & Baxter, 2000; Schunk & Pajares, 2005; Velayutham & Aldridge, 2013). For instance, Pintrich et al. (2000) found that some effective metacognitive strategies, such as planning learning activities, monitoring learning processes and regulating cognitive methods, were highly employed by SR learners. Schunk and Pajares (2005) revealed that students who have high efficacy usually work harder, evaluate their progress more frequently, and engage in more self-regulatory strategies that prompt success in school. In addition, Velayutham and Aldridge (2013) suggested that students' cohesiveness, investigation and task orientation were the most influential predictors of their motivation and SR in learning science. They furthermore revealed that goal-orientation learning in science, task value and self-efficacy significantly influenced students' SR in learning science. More currently, Wang, Chen, Lin, and Hong (2017) conducted structural equation modelling analyses and found that college students' SR had a strong and direct relation to students' positive thinking (ß = .83) and learning motivation (ß = .86). Despite the fact that many studies have emphasised the importance and benefits of SR on student learning, rather less attention has been given to exploring how SR and CT can be developed in science teaching and learning. It has been argued that students from different educational levels have different ways of motivating their academic performance and behaviour (Boekaerts, 2003). The present study was designed to explore students' perceptions of CT and SR after they were involved in a three-semester intervention.

How does CL play an important role for adolescents' learning in science?

CL has been described as the instructional use of small groups in which students work together to maximise their own and each other's learning (Johnson & Johnson, 2003; Tanner, Chatman, & Allen, 2003). CL is widely recognised as an effective pedagogical practice that promotes learning and socialisation among students from kindergarten through college and across different subjects (Johnson & Johnson, 2003; Serrano & Pons, 2007; Sharan, 2010; Thurston et al., 2010). It has been argued that CL experiences are crucial to preventing and alleviating many of the academic and social problems related to children, adolescents and young adults (Gillies, 2014; Johnson & Johnson, 2003).

Numerous studies have investigated the effects of CL (e.g. Gillies, 2011; Jenkins, Antil, Wayne, & Vadasy, 2003; Pons, González-Herrero, & Serrano, 2008; Slavin, 2013; Stevens, 2003). For example, CL was used successfully to promote reading and writing achievement in secondary school English (Slavin, 2013), learning performance for academically delayed students (Stevens & Slavin, 1995), problem-solving in mathematics (Pons et al., 2008; Slavin, 2013) and higher-order thinking skills (Gillies, 2011). Other benefits attributed to the use of CL are promoting self-esteem and confidence, and building a supportive learning environment with better classroom success rates (Jenkins et al., 2003). In addition, it has been used as a teaching strategy to assist students to manage conflict (Cowie, 1995), to help students who have been identified as bullies learn appropriate interpersonal skills (Cowie, 2004), and to train teachers embedding CL into their classroom pedagogy (Pons, Sharan, Serrano, Lomeli, & Buchs, 2013). In addition, CL has been shown to enhance students' willingness to work cooperatively and productively with others with diverse learning and adjustment needs, and to enhance intergroup relations with those from culturally and ethnically different backgrounds (Johnson & Johnson, 2003).

In a CL group, students learn to share ideas and perspectives, listen to each other with particular emphasis on how things are said, give and receive help, seek ways to resolve difficulties and actively work together to construct new understanding (Johnson & Johnson, 2003). It seems that CL facilitates a shift in the pattern of typical exchange away from a teacher-dominated discourse towards a more student-centered, open discourse (Day & Bryce, 2013). There is no doubt that CL is wide-spread and its numerous successes has led to it being acclaimed as one of the greatest educational innovations of recent times (Gillies, 2014). In general, the role of a CHC teacher is more than simply being a lecturer. He/she also has moral role as a 'parent' with students who have a 'collectivist obligation to behave with the socially accepted way' (Watkins & Biggs, 2001, p. 282). Therefore, we purposefully designed a supportive classroom where learning is dependent on the socially structured exchange of information between students within groups (Johnson & Johnson, 2003), in which students are held responsible for learning with their teammates (Slavin, 2013), and are motivated to increase the learning of others (Hancock, 2004).

SSI discussions for student's science learning

SSIs are controversial scientific topics that involve social and ethical considerations (Sadler, 2004; Zeidler & Sadler, 2007). Morris (2014) also claimed that including SSI events in the science curriculum is a well-established teaching technique to encourage critical discussion of ethical and moral dilemmas. Day and Bryce (2013) found that SSI discussion within the science classroom can contribute to the development of pupils' scientific literacy by exposing students to contemporary science content and allow them to experience and practice CT skills. The ability of individual members of the public to critically examine and make thoughtful decisions regarding such issues is recognised as a major goal for science education internationally (OECD, 2001); it obviously supports the notion that the science education is in a unique position to help young people develop skills which would enable them to respond critically to media reports on issues with a science dimension (Day & Bryce, 2013). While there are many research studies investigating how SSI can be used to promote student argumentation, little research exists which longitudinally examines the development of students' perception of CT and SR.

The aims of the current intervention are to enable adolescents to develop as scientifically literate citizens, who are able to hold and defend informed views on science, moral, ethical, economic and environmental issues related to science. With this background, we designed an innovational science teaching strategy, and created a cooperation-driven learning environment that would be sufficiently open to enable, and indeed encourage students to publicly verbalise individual perceptions of CT and SR within groups.

The following two research questions guided the design of this study:

(1) Does the CDSSI intervention impact the experimental group (EG) students' perceptions of CT and SR?

(2) What are the trends of the EG students' perceptions of CT and SR over the three-semester research period?

Methods

Research design

The effect of the CDSSI intervention was examined in a four-wave pre-post-follow-up comparison-group design (i.e. in the beginning of the first semester and at the end of the first, second and third semesters) using the CT and SR questionnaires at all measurement times. Each unit of the intervention took place in a 120-min block, which was carried out within a week. The intervention was applied for three semesters. All participants completed the pre-test at the beginning of the first semester and subsequently at the end of each semester. Classroom observations of eight target students were conducted during each unit. In addition, a follow-up interview was conducted one month after each semester's intervention to examine the effects of the CDSSI on the EG students' CT and SR (Turner, 2010).

Participants and setting

This study took place in Kaohsiung City, Taiwan. The EG consisted of 49 grade 7 students who were randomly selected to attend a 3-semester 36-week 72-hour CDSSI intervention. Another 49 grade 7 students from the same school were randomly recruited as the comparison group (CG). All the students come from diverse socioeconomic status families and have similar psychological and physical educational environments. Informed consent forms were sent to classroom teachers, science teachers, parents and students inviting them to participate in the study (quasi-experiment, survey, observation and potential interview). The consent forms were approved by the university's research ethics committee, explained the purpose of the study and stated that all participants could withdraw at any time without negative effect that the questionnaire and its responses were anonymous, that the data would be kept confidential, and that the results would not be compared or identified personally. Four boys and four girls from the EG with the lowest scores on either CT or SR were recruited for weekly observation during the intervention. In addition, these eight target students and two teachers (one classroom and one science teacher) were interviewed individually one month after each semester's intervention by the corresponding author.

Development and validation of instruments

Student Questionnaire (SQ)

The SQ includes three sections: the first section addresses participants' demographic items (i.e. gender, age, average scores in science previous semester science course); the second section includes the 56-item Chinese version of Critical Thinking Scales (CTS) derived from the Chinese version of the California Critical Thinking Disposition Inventory (CCTDI) (Yeh, 2002). The Chinese CCTDI had an adequate Content Validity Index (Lynn, 1986) of 0.85 and an overall internal reliability (Cronbach's $\alpha = 0.79$). Yeh

(2002) revealed that the psychometric equivalencies across Chinese and English CCTDI showed similar content validity and reliability. Although the translation adequacy of Chinese CCTDI needs to be improved, there is evidence that it is useful for evaluating CT dispositions. In this study, all participants were asked to rate each CTS item using a 5-point Likert scale (5 = strongly agree … 1 = strongly disagree). A panel of science educators examined these items to explore their construct validity. The CTS contains 7 factors: the first factor is *truth-seeking, it* included 8 items with a possible total score range of 8–40; a sample item is: 'I can find evidence from support information'; the second factor is *open-mindedness*, it included 8 items with a possible total score range of 8–40; a sample item is: 'I can think out some alternative solutions'; the third factor is *analyticity*, it contained 8 items with a possible total score range of 8–40; a sample item is: 'I can analyze data from key Socio-scientific issue (SSI)'; the fourth factor is *systematicity*, it included 8 items with a possible total score range of 8–40; a sample item is: 'I am able to think systematically'; the fifth factor is *self-confidence,* it contained 8 items with a possible total score range of 8–40; a sample item is: 'My critical thinking skill is superior to other students in my class'; the sixth factor is *inquisitiveness,* it included 8 items with a possible total score range of 8–40, a sample item is: 'I am always curious to learn science', and the seventh factor is *maturity*, it contained 8 items with a possible total score range of 8–40; a sample item is: 'I prefer to think carefully about science knowledge'. We performed a confirmatory factor analysis (CFA) to evaluate how well the hypothesised models fit the data of Taiwanese secondary school student samples. All the factor loadings were significant (i.e. loadings range from 0.66 to 0.90), and the indexes of fit statistics indicated a good fit to the data ($\chi^2_{(56)} = 91.206$, $p = .002$, $\chi^2/df = 1.629$, GFI = .901, CFI = .955, RMSEA = .075, PCLOSE = .076). Overall, the results showed that the measured model fit the data quite well (Hu & Bentler, 1999). The CTS was used to measure participants' perceptions of CT, but not their actual CT skills.

The third section includes the 63-item Chinese version of the Self-Regulation Questionnaire (SRQ) developed by Brown, Miller, and Lawendowski (1999). The SRQ had an adequate construct validity and internal reliability (Cronbach's $\alpha = 0.91$). A Brislin cross-cultural translation model (1986) was conducted on the SRQ. Participants were asked to rate each SRQ item using a 5-point Likert scale (5 = strongly agree … 1 = strongly disagree). The SRQ contains seven factors: factor 1: *receiving the information* including 9 items with a total score range of 9–45; a sample item is: 'I have sufficient ability to search information from multiple sources'; factor 2: *evaluating the information* containing 9 items with a total score range of 9–45; a sample item is: 'I have confidence to evaluate reliability and validity of the information'; factor 3: *triggering change* including 9 items with a total score range of 9–45; a sample item is: 'I can handle things that are out of control'; factor 4: *searching for options* containing 9 items with a total score range of 9–45; a sample item is: 'I can find alternative strategies to solve difficult situations'; factor 5: *formulating a plan* containing 9 items with a total score range of 9–45; a sample item is: 'I can design a plan without any difficulties'; factor 6: *implementing the plan* includes 9 items with a possible total score range of 9–45; a sample item is: 'I can implement a plan without any problems'; and factor 7: *assessing* including 9 items with a total score range of 9–45, a sample items is: *I can assess the effects of the whole plan*. A CFA was used to evaluate how well the hypothesised models fit the Taiwanese students. The results showed that all the factor loadings were significant (i.e. loadings range from 0.43

to 0.92), and the indexes of fit statistics indicated a good fit to the data ($\chi^2_{(56)} = 190.19$, $p < .001$, $\chi^2/df = 3.396$, GFI = .811, CFI = .860, RMSEA = .147, PCLOSE = .000). Overall, the results showed that the measured model fit the data very well (Hu & Bentler, 1999). The SRQ was used to measure participants' perceptions of SR, but not on their actual SR skills.

Students' classroom observation form

The student observation form was developed by Hong et al. (2012) based on Pellegrini's 'Classroom Observation Coding Schedule indicating that good descriptions meet the criteria of being reliable and valid and are generally used in either experimental or field setting' (1996, p. 7). The form was designed with a six-category coding system to gather information on target students' behaviours regarding their CT and SR. The categories are: CTa: finding evidence to support individual arguments; CTb: using open-minded thinking; CTc: having individual assertions; SRa: if having difficulty the individual will find someone to assist him/her directly; SRb: never gives up; SRc: doing everything to provide the best response. Weekly observations were conducted by two graduate students majoring in science education; they were assigned specific target students to observe over the 36-week intervention. The time-sensitive observations allowed comparisons of student performance over the intervention's three-semester duration so as to detect students' subtle changes on CT and SR during the CDSSIs intervention. The frequency of students' target behaviours was calculated by totalling the numbers of observed behaviours.

Students, classroom and science teachers' interview protocols

Semi-structured interview protocols were developed to further investigate the effects of the CDSSI on eight target students and their classroom and science teachers. These respondents were individually interviewed by the investigators for 20–35 minutes using specific protocols at the target students' schools. According to Bandura's reciprocal determinism (1986), a person's behaviour both influences and is influenced by personal factors (i.e. characteristics and behaviours) and the social environment. Therefore, we designed a multiple data collection process (i.e. four-waves of surveys, weekly classroom observations of students and three waves of interviews with students, classroom teachers and science teachers) to compare target students' changes in their perceptions of CT and SR after attending the CDSSI.

A sample student interview question was: 'Can you describe any changes you experienced while participating in this intervention for me? Please give me some examples to describe any differences in your thinking and behaviors while participating in the approach?' A sample interview question for classroom and science teachers was: 'Did you perceive any differences in the target students after they attended the intervention? Please give me some examples to describe any differences in your students' thinking and behavior during the study?' All interviews were audiotaped and transcribed into searchable text files.

Treatment and procedure

CL has been shown to be a widely recognised pedagogical practice to promote learning and socialisation among students from kindergarten through college and across different subjects (e.g. Johnson & Johnson, 2003). We modified CL and added SSI content into the intervention, which named 'cooperation-based SSI intervention' (CDSSI). The EG students participated in a 36-week (72 hours) CDSSI intervention on Monday mornings from 8:00 to 10:00am in a typical junior high school science laboratory while the CG students were in their regular science lessons in their classrooms. The regular science lessons were taught in a lecture style in which the teacher explained the concepts from the textbook and the students received the knowledge passively. In the EG the students were grouped into sets of 5–6 students. They followed the typical activity outlined in the next paragraph, and had to cooperatively complete weekly group worksheets with the SSI questions, do simple investigation reports, present reasons and findings in front of the whole class, and accept critique publicly during the intervention. The current study covered 18 SSI topics (e.g. construction of high-speed rail, earthquake prediction, brain-neuro technology, nuclear power issue, genetically modified food, global warming and renewable energy supplies) involving 36 activities over the 36 weeks. The details of the six stages of teaching and learning activities of a typical CDSSI teaching module are shown as Appendix 1. Multiple strategies such as teacher demonstrations and presentations, video watching, whole classroom discussions, small group CL, student presentation and evaluation of group consensual arguments, and teacher concluding remarks were used in the intervention.

Data analyses

First, we performed CFAs to evaluate how well the hypothesised models fit the data of student samples; second, analyses of covariance (ANCOVAs) using the pre-test results as the covariants were conducted to determine if there were any main effects for the treatment between the EG and CG post-test results for CT and SR. Third, paired-wise *t*-tests were used to explore the differences between pre-tests and post-tests for EG students' CT and SR in learning science. Finally, content theme analysis (Patton, 2002) was used to analyse the weekly observations and individual interview results. In the current study we read and annotated transcripts repeatedly to familiarise ourselves with the data. Then, we identified the key themes or topics which were repeated across the data, including truth-seeking, open-mindedness, analyticity, systematicity, self-confidence, inquisitiveness, maturity, receiving the information, evaluating the information, triggering change, searching for options, formulating a plan, implementing the plan and assessing. Moreover, we developed a coding scheme to identify and determine the pieces of data which corresponded to each theme. In addition, we report effect sizes for statistical significance results, allowing readers to interpret the results (Kirk, 2001).

Results

The results are reported in an ordered fashion to establish the similarity between the EG and CG at the outset of the study and then to address each of the two research questions. The quantitative results were reported for the research questions followed by the qualitative assertions to provide insights on the numerical outcomes.

RQ1: Does the CDSSI intervention impact the EG students' perceptions of CT and SR?

The ANCOVAs with the pre-test CT and SR means as the covariant were used to explore the treatment main effect on post-test CT score (Appendix 2). The results indicated that the adjusted post-test scores of the EG students' on perceptions of CT were not significantly different from the CG students at the end of the first semester ($F = 3.37$, $p = .070$, $\eta_p^2 = .042$. However in the second ($F = 6.76^{**}$, $p = .011$, $\eta_p^2 = .080$) and third ($F = 14.98^{***}$, $p < .001$, $\eta_p^2 = .141$) semesters the EG students' scores were significantly higher than the CG students'. The gaps between the two groups were getting larger and more significant from the second to the third semester.

In addition, we found that the adjusted post-test scores of the EG students' perceptions of SR scores were significantly higher than the CG students' perceptions in the first ($F = 5.11^{*}$, $p = .027$, $\eta_p^2 = .061$) and in the third ($F = 25.98^{***}$, $p < .001$, $\eta_p^2 = .232$) semesters, but there was no significant difference in the second semester ($F = 3.72$, $p = .057$, $\eta_p^2 = .046$).

Observation findings

Lee was a low self-perception CT boy; he highly enjoyed and actively participated in group discussions during the intervention, he made significant progress at the later periods of the study, his growth in self-perception CT went from 5.40% (first semester) to 14.30% (second semester) and to 51.40% (third semester), and he made a gradual improvement on self-perception SR from 37.50% (first semester) to 56.10% (second semester) to 66.80% (third semester) over the study time.

Chen was a low self-perception SR girl; she was highly involved in all activities and gradually engaged in discussion with group members. She made gradual and significant progress over the study time, her enhancement in self-perception of CT went from 6.40% (first semester) to 18.60% (second semester) to 32.8% (third semester), her self-perception of SR went from 3.60% (first semester) to 33.50% (second semester) to 62.90% (third semester).

The eight target students' behaviours were summarised and plotted on bar graphs to illustrate behaviour changes in self-perception of CT and SR across the three semesters. Early-late performance comparisons indicate increases across all of the low self-perception CT or SR target students. Two representative graphs (Lee and Chen) are shown to demonstrate their dramatic improvement in CR/SR; in addition, graphs of two other target students (Wang and Lin) show continuous improvement in their self-conception of CT/SR.

Lee was a low self-concept CT boy; he highly enjoyed and actively participated in group discussion during the intervention, and he made dramatic progress at the later periods of the study, his enhancement in self-conception of CT went from 5.40% (first semester) to 14.30% (second semester) and to 51.40% (third semester); he also made gradual improvement on his self-conception of SR from 37.50% (first semester) to 56.10% (second semester) to 66.80% (third semester) over the study time.

Chen was a low self-conception SR girl; she was highly involved in all activities and gradually engaged in discussion with group members, she made dramatic progress over the study time, her enhancement in self-conception of CT went from 6.40% (first semester) to 18.60% (second semester) to 32.8% (third semester), her self-conception of SR went from 3.60% (first semester) to 33.50% (second semester) to 62.90% (third semester).

Wang was a low self-conception CT girl; she slowly got involved in group discussion during the intervention; she made continuous progress during the later periods of the study, her enhancement in self-conception of CT went from 7.30% (first semester) to 9.20% (second semester) and to 14.10% (third semester), and she made gradual improvement in self-conception of SR from 10.90% (first semester) to 24.70% (second semester) to 36.40% (third semester) over the study time.

Lin was a low SR boy; he was moderately involved in all activities and followed team members' direction during the team sessions; he made continuous progress over the study time, his in self-conception of CT went from 6.20% (first semester) to 13.00% (second semester) to 16.50% (third semester), his self-conception of SR went from 4.30% (first semester) to 10.10% (second semester) to 22.60% (third semester) (Figures 1–4).

Interview results

The interviews with the eight target students and their classroom and science teachers provided more evidence to support the ANCOVAs findings (Appendix 3). Most of these responses indicated either dramatic or continuous improvement in self-conception of CT and SR. The interview results from four representative students (i.e. Lee, Wang, Chen and Lin), who obtained the lowest scores on either self-conception of CT or SR on the pre-test, are shown in Appendix 3. Their self-reported improvement in self-conception of CT and/or SR was corroborated by comments from their science teacher and classroom teacher. As can be seen in Appendix 3, all of the four target students had either superficial thinking or negative and passive attitudes towards learning science in the beginning stage of the study. At a later phase of the CDSSI teaching intervention,

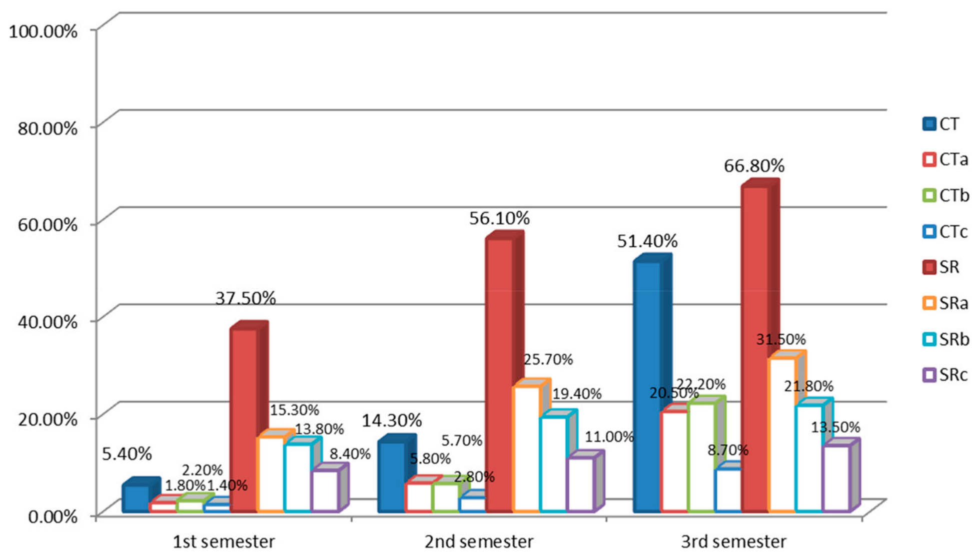

Figure 1. Lee's observation results (i. e., Lee had a low CT in the beginning, then he made a dramatic improvement on his CT at a later phase). Note: CT: critical thinking total score; CTa: finding out evidences to support individual arguments; CTb: with an open-mind thinking; CTc: having individual assertion; SR: Self-regulation total score; SRa: while having difficult, individual will find someone to assist he/she directly; SRb: never give up; SRc: doing everything is the best.

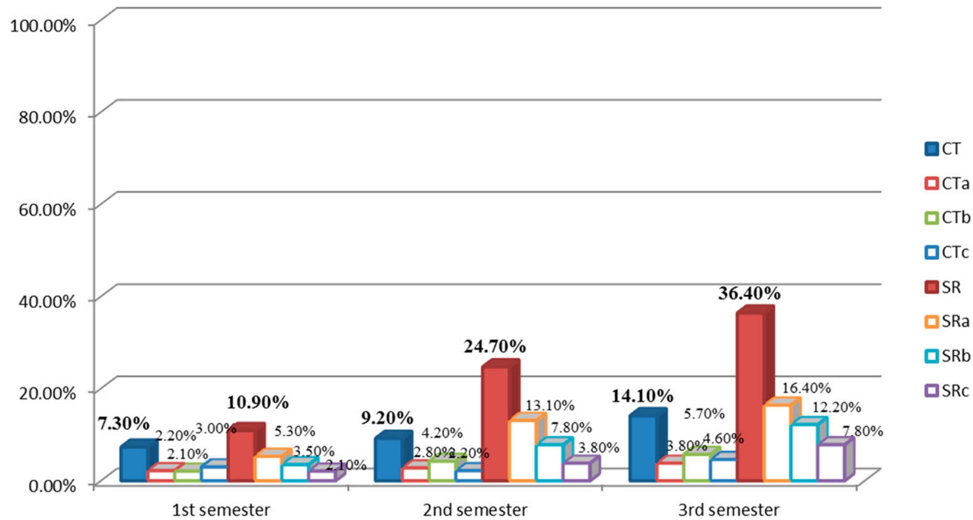

Figure 2. Wang's observation results (i.e. Wang had a really low CT in the beginning, whereas, she made a slight and continuous improvement on her CR at a later phase). Note: CT: critical thinking total score; CTa: finding out evidences to support individual arguments; CTb: with an open-mind thinking; CTc: having individual assertion; SR: self-regulation total score; SRa: while having difficult, individual will find someone to assist he/she directly; SRb: never give up; SRc: doing everything is the best.

Lee and Chen made a dramatic improvement in CT and/or SR, and Wang and Lin presented a small but continuous enhancement. Lee and Chen became more actively engaged in CT, reflective learning and making positive contributions towards group

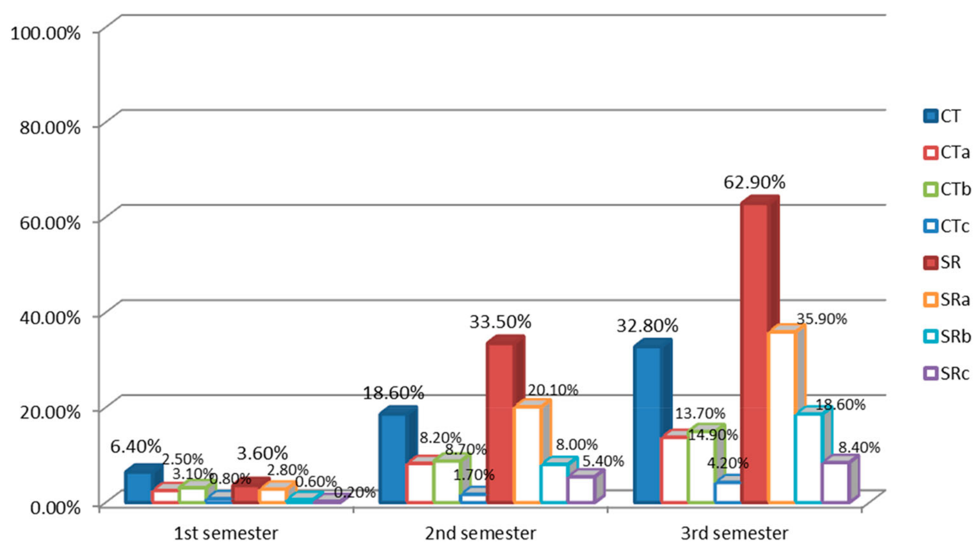

Figure 3. Chen's observation results (i.e. She had a low SR in the beginning, then she made a dramatic improvement on her SR at a later phase). Note: CT: critical thinking total score; CTa: finding out evidences to support individual arguments; CTb: with an open-mind thinking; CTc: having individual assertion; SR: self-regulation total score; SRa: while having difficult, individual will find someone to assist he/she directly; SRb: never give up; SRc: doing everything is the best.

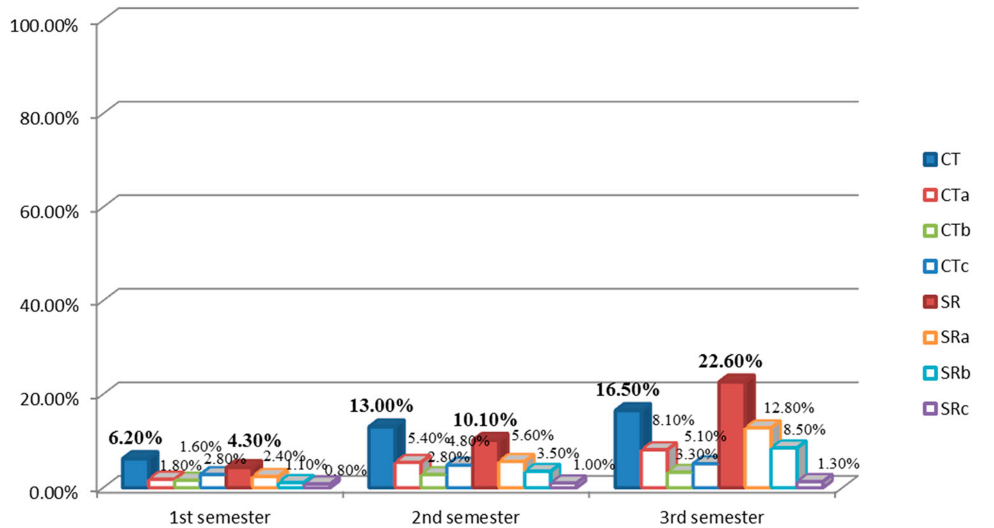

Figure 4. Lin's observation results (i.e. He had a very low SR in the beginning, we found that he made a slight and continuous improvement on his SR at a later phase). Note: CT: critical thinking total score; CTa: finding out evidences to support individual arguments; CTb: with an open-mind thinking; CTc: having individual assertion; SR: self-regulation total score; SRa: while having difficult, individual will find someone to assist he/she directly; SRb: never give up; SRc: doing everything is the best.

discussions. Additional checks of their classroom worksheets revealed that the four target students made progress in the second and third semester not only in providing more arguments to support their claims for SSI, but also on the quality level of their arguments. Moreover, both Wang and Lin were found to prefer providing their questions in front of whole class, and sometimes they asked questions relating to the Internet/Line information.

RQ2: How did the EG students' perceptions of CT and SR develop and change over the three-semester research period?

We conducted pair-wise *t*-tests to examine the differences between the EG students' pre- and post-test scores on their self-perception of CT and SR (Appendix 4). The *t*-test results in Appendix 4 reveal that the post-test means (third semester) of the EG students' self-perception of CT ($t = -3.54$**, $p = .001$, $d = .46$), and on the three factors of *self-confidence* ($t = -3.23$**, $p = .002$, $d = .56$); *inquisitiveness* ($t = -2.16$*, $p = .036$, $d = .31$) and *maturity* ($t = -4.43$***, $p < .001$, $d = .72$) were significantly higher than their pre-test means (first semester). In addition, the EG students' post-test scores on self-perception of SR means in learning science ($t = -2.42$**, $p = .020$, $d = .31$) and on the three factors of *evaluating the information* ($t = -2.81$**, $p = .007$, $d = .32$), *searching for options* ($t = -2.92$**, $p = .005$, $d = .42$), and *assessing* ($t = -4.25$***, $p < .001$, $d = .62$) were significantly higher than their pre-test mean scores. These significant improvements of students' self-perceptions of CT and SR scores provide evidence to support the effect of the CDSSI intervention.

Discussion and educational implications

This study provides two noteworthy findings that give insights into effective strategies for developing junior high school students' self-perceptions of CT and SR. The potential reasons and explanations for this are discussed in the following paragraphs.

Promoting students' self-perception of CT through the CDSSI intervention

The quantitative (i.e. four-wave pre-post survey) and qualitative (i.e. weekly classroom observations, three waves of target students, their classroom, and science teacher's interviews) results were consistent which helped to confirm inferences regarding the relationships between the intervention and the measured outcomes. The study also provided evidence to support the feasibility of implementing the CDSSI intervention.

While previous studies (Lee et al., 2013; Littlejohn, 1996; Vygotsky, 1978) asserted that CT is socially constructed and developed collaboratively through students' language-mediated social interactions with peers and teachers, this study further identified that students' self-perceptions of CT and/or SR can be cultivated through supportive, interactive and reflective learning opportunities such as the CDSSI discussions. Students were encouraged to work together cooperatively without any personal competition or blame within group members. These positive findings were echoed by Day and Bryce's (2013) study which showed that CL facilitates a shift in the typical exchange pattern away from a teacher-dominated discourse towards a more student-centered, open disclosure. Our qualitative findings of target student-Lee's and his teacher's interview results and Lee's classroom observation results (cite from Appendix 3 and Figure 1) also indicated that students were more engaged in sharing, evaluating, reflecting and achieving consensus on variety of arguments. The cohesiveness of small group CDSSI discussions allow students to practice listening to team members (i.e. open-mindedness and inquistiveness), evaluate and reflect on peers' comments (i.e. analyticity and systematicity), and to seek consensus within their group (i.e. truth-seeking). Consequently, students become more confident (i.e. self-confidence) about their CT skills.

The other essential factor is that the CDSSI teaching model might lead the EG students' to increase their perceptions of CT. This finding is partially consistent with Erwing's components of CT which were presented in 2002. In the current study, students learned to clarify the problem from the teacher opening statements through identification of a focus topic process. Students learned to identify the background knowledge supporting any declared claim from watching videos related to the weekly topics processes. They also tried to recognise unstated assumptions in a statement developed through the asking and discussing process. The opportunities for distinguishing facts from opinions and inferences along with checking credibility and validity of evidence enabled the students to judge and make decisions on SSI issues and to improve their logical thinking and reasoning.

This study adds value to the literature by providing empirical evidence and piloting an effective teaching approach for promoting junior high school students' CT. We found that EG students' perceptions of CT total scores, *self-confidence*, *inquistiveness* and *maturity* were significantly improved through the CDSSI intervention. The results show that the CDSSI teaching model plays an important role in cultivating students' cognitive understanding in learning science (Chiu, 2009). Given the finding (e.g. Goodlad, 1984; Yang & Chung, 2009) that adolescents fail to engage in CT and higher-order thinking and have insufficient competency for future society and globalisation, the initial fruitful findings of this study provide a signal for Taiwanese learners. These learners, who are fostered in an Eastern traditional culture with a collectivism ideology, have the potential to cultivate their CT through the use of a well-structured CDSSI teaching model.

Cultivating adolescent learners' perceptions of SR needs to emphasise the intermediate phases of learning

From the ANCOVA results, we found that EG students' perceptions of SR were significantly higher than their counterparts in the first and third semesters. This result was partially supported by Spiro, Feltovich, Jacobson, and Coulson (1991) who posited that self-regulation learning (SRL) may promote students' cognitive flexibility by enabling them to examine problematic issues based on the structure of their own existing bodies of knowledge and based on their current understanding of knowledge from different points of view. The CDSSI teaching model was similar to SRL. It not only integrated SSI, but also conducted language-mediated social interactions within a cooperation-driven learning environment. The benefit of CL has been approved by Campione, Shapiro, and Brown (1995). They found that when students are undertaking cooperative group work, learning may proceed with knowledge on how the learning relates to prior learning, the learners' self-awareness about what they are doing and talking about and thinking through a problem during group discussion. A possible mechanism for this might be that cooperative group work enables and facilities a greater volume of engaged and successful practice, leading to consolidation, fluency and automaticity of core skills (Thurston et al., 2010).

In addition, we found the EG students' perception of SR was better and significantly higher than their counterparts after the third semester of intervention. It might relate to the interesting and fruitful CDSSI intervention. Typical science classes in current Taiwan are more academically oriented and less related to student personal experience. According to Lee, Tsai, and Chai (2012), science teaching in Taiwan has traditionally focused on science content – the bedrock of the curriculum and school science examinations, which might relate to students' negative attitudes and underdeveloped thinking in science. In addition, it has been found that the EG students' perception of SR is an important affective factor related to a positive behavioural effect (i.e. as shown in the quantitative and qualitative results). The affective states are often depicted as operating directly on psychosocial functioning with a positive tendency producing beneficial effects. The results of this study revealed that most of the EG participants gradually and significantly increased their positive emotional experiences through the CDSSI. As adolescents are in a taxing transitional phase that presents a host of new challenges (Bandura, 1997; Eccles & Midgley, 1989), they need to manage major biological, educational and social role transitions concurrently while also learning how to deal with puberty changes. Structural school environments, enlarged peer networks and emotionally invested partnerships become important. Thus, in this current study, we provided student-centered instruction which allowed team members to work together and learn from others. Students were inspired to pay more attention to personal tasks, such as organising their work, setting team goals, seeking help, managing their time, doing research, answering worksheets and planning individual learning activities. All of the above learning environment activities are supportive of the positive development of student affective perceptions.

The above cognitive and affective engagements were consistent with Zimmerman's (2002) assertion. He believed that students' perceptions of SR are essential for classroom stimulation place constraints on changing learners' SRL (Zimmerman, 2008). Moreover, the EG students' actions of *evaluating the information*, *searching for options* and *assessing* the variety of arguments were supportive of enhancing students' SR in learning science.

Limitations and educational recommendations

Readers are reminded that self-report questionnaires might raise the possibility of social desirability effects (Rowley, Kurtz-Costes, Mistry, & Feagans, 2007). The SQ used in this study can only assess the temporal stability of students' perceptions, such as their behaviour intentions. In addition, despite using triangulated data collection process(i.e. four-wave survey, weekly classroom observation, and three-wave interview), the assessment of students' perceptions of CT and SR through the self-report questionnaire and classroom observation, students' and teachers' interviews might not directly relate to their actual skills of CT and SR. Despite these limitations, our findings provided empirical evidence of how students' perceptions changed over time and the potential usefulness of implementing the Chinese version of Critical Thinking and SR with secondary school students. These instruments are highly recommended to be used for Asian countries' secondary school students. It would be of great interest to see a wide range of exploration of students' perceptions of CT and SR.

In future studies, a three-year longitudinal research design would allow us to compare and observe intra-individual changes and development in students' perceptions of CT and SR across this essential transition to early adulthood (Rowley et al., 2007).

Conclusion and suggestions

In summary, the use of a quasi-experimental three-semester longitudinal design allowed us to shed light on the effects of the CDSSI teaching model. This paper contributes to the literature by illustrating how the CDSSI teaching model can effectively cultivate students' perceptions of CT and SR.

This study can serve to remind school science teachers to develop more effective and innovative instruction to inspire adolescent learners to focus on their self-perception of CT and SR in an information-rich knowledge-oriented society (Chiu, 2009; Zimmerman, 2001). Obviously, the adolescent learners perceived that they have self-confidence, inquisitiveness and maturity related to CT; in addition, their evaluating of the information, searching for options and assessing SR might significantly improve through the well-structured 36-week 3-semester 18-unit CDSSI teaching model.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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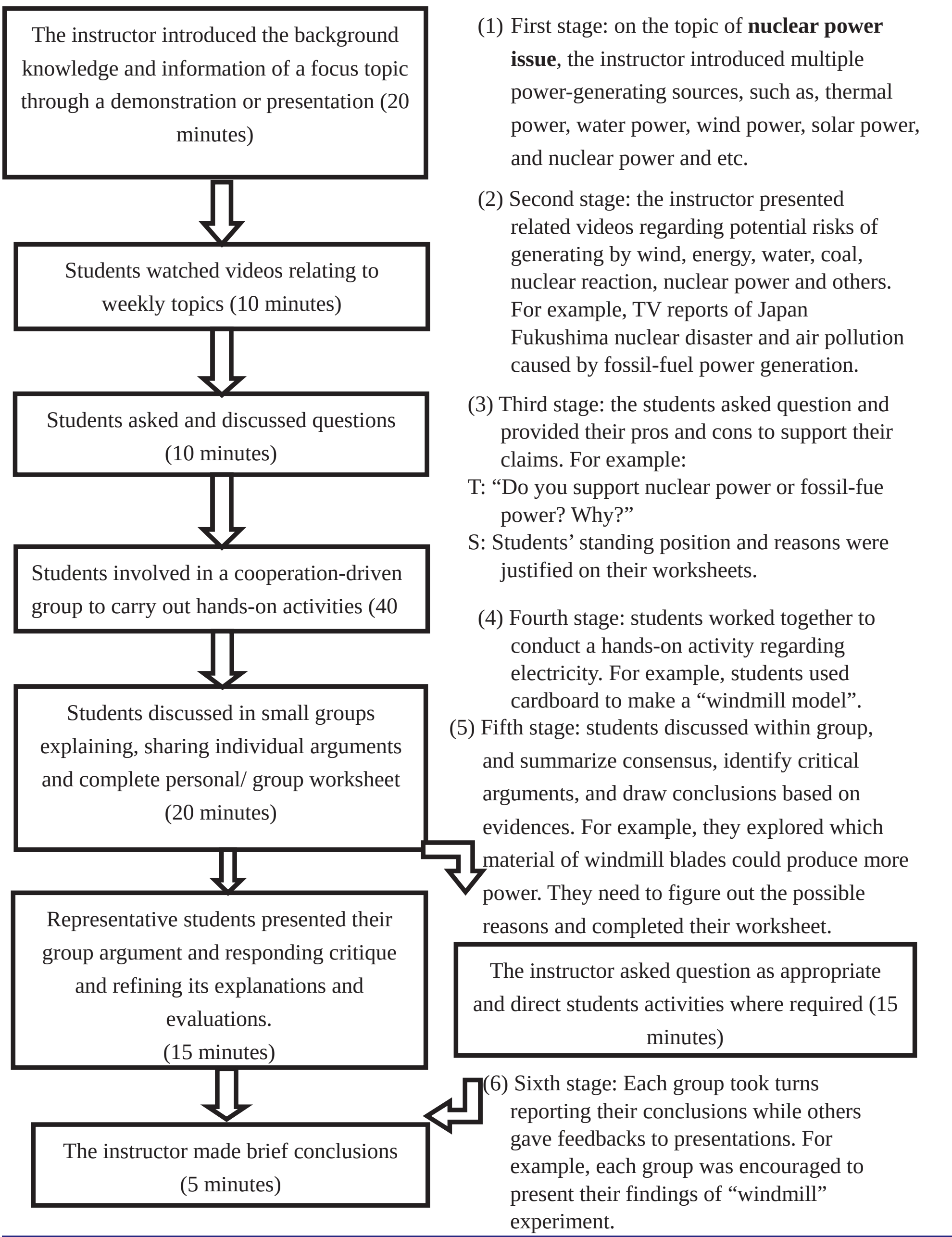
Appendix 1. A typical teaching mode of CDSSI.



Appendix 2. Results of ANCOVAs of critical thinking (CT) and self-regulation in learning science (SR) mean scores between groups.

Dimensions	Semester	Groups	*N*	Mean of pre-test	Mean of Post-test	*SD*	Adjusted post-test mean	Adjusted post-test SE	*F*-value	*p*-Value	η_p^2
[a]CT	First semester	Exp.	43	183.57	192.27	25.55	191.58	2.91	3.37 *n.s.*	.070	.042
		Com.	37	186.09	184.40	20.14	185.19	3.14			
	Second semester	Exp.	49	183.57	194.25	21.67	192.87	2.35	**6.76***	.011	.080
		Com.	32	186.09	184.67	22.74	186.67	2.83			
	Third semester	Exp.	48	183.57	194.72	23.17	194.25	2.47	**14.98*****	<.001	.141
		Com.	46	186.09	181.03	15.09	181.52	2.53			
[b]SR	First semester	Exp.	43	210.28	223.53	28.77	223.43	3.20	**5.11***	.027	.061
		Com.	37	210.76	212.89	24.79	213.00	3.45			
	Second semester	Exp.	49	210.28	219.15	27.34	218.86	3.06	3.72 *n.s.*	.057	.046
		Com.	32	210.76	209.74	23.49	210.19	3.79			
	Third semester	Exp.	48	210.28	219.19	25.21	219.13	2.51	**25.98*****	<.001	.232
		Com.	46	210.76	200.24	15.24	200.31	2.71			

[a]CT, critical thinking total score.
[b]SR, self-regulation in learning science total score; bold numbers indicates a significant correlation between the CT and SR. small effect size of η_p^2: .01; medium effect size of η_p^2: .059; large effect size of η_p^2: .138 (Cohen, 1988).
*$p < .05$.
**$p < .01$.
***$p < .001$.

Appendix 3. The interview descriptions from four representative target students and their classroom and science teachers.

Critical thinking (CT)

Target Students	Phase	Interview results from students, classroom teacher and science teacher
Lee (a low CT target students, he made a dramatic improvement at a later phase)	At an early phase	1. Lee was a self-centered boy; he never considers about others' views. Usually, he insisted an opposed comment but could not provide any clear justification (cite from Lee's science teacher's interview, 08 October 2014). 2. He responded to problem-solving issues with 'yes' or 'no' answers without any through consideration. He never provided any alternative possibilities in the group discussion section (cite from Lee's classroom teacher's interview, 12 October 2014)
	At a later phase	1. Lee pointed out some mistakes at my science class regarding the air pollution. He tried to provide solutions to solve the environmental problems. He is more sensitive and starts to negotiate with team member in themselves in solving national and global environmental problems (cite from Lee's science teacher interview, 25 January 2016) 2. I found that Lee considered thoughtfully and provided evidences to support his ideas. If he disagreed with other's opinions, he proposed his viewpoint directly without any hesitation (cite from Lee's classroom teacher interview, 20 January 2016) 3. I asked questions more often during the group discussion section, because our team members helped each other all the time. I believed that I am able to think deeply and critically while attending the science class. In

(*Continued*)

Continued.

Target Students	Phase	Interview results from students, classroom teacher and science teacher
		addition, it is important to show our opinions in front of the class, no matter what the answer is correct or wrong (cite from Lee's interview, 22 January 2016)
Wang (a low CT target student, she made a slight and continuous improvement through intervention)	At an early phase	1. Actually, she always followed other students' recommendations and never provided any comments or suggestions at my class (cite from Wang's classroom teacher interview, 12 October 2014) 2. She responded question directly and answered study sheet with simple answer but not having any further consideration (cite from Wang's science teacher interview, 08 October 2014)
	At a later phase	1. When she came up with ideas, she preferred telling me in front of whole class. Her dramatic improvement was impressive to me (cite from Wang's classroom teacher's interview, 20 January 2016) 2. I would like to discuss with other team members because I learned from the process of argumentation. I felt that I am getting smarter. Sometimes, I can propose good suggestions for my team (cite from Wang's interview, 22 January 2016)

Self-regulation

Student	Phase	Interview results from students, classroom teacher and science teacher
Chen (a low SR target student, she made a dramatic improvement at a later phase)	At an earlier phase	1. She never actively joined the discussion at my science class (cite from Chen's science teacher interview, 08 October 2014) 2. Chen was a passive learner at my class. Her attitude towards science was really negative. She never turned in the assignments on time (cite from Chen's science teacher interview, 08 October 2014) 3. She was only interested in watching video but not on my lectures (cite from Chen's science teacher interview, 08 October 2014)
	At a later phase	1. Chen's grades improve a lot, from the rank 15 to rank 3 or 4. She borrows books from his English teacher actively. I found that Chen actively joined most of learning activities at my class (cite from Chen's classroom teacher interview, 20 January 2016). 2. She made a great improvement on handling her homework since attending the CDSSI class. She was willing to participate in discussion and talk to other team members at my class; sometimes, she provided valuable information (cite from Chen's science teacher interview, 25 January 2016) 3. I really enjoyed engaging in team works. We shared opinions and strategies of solving problems and handling hard tasks during the group discussion. For examples, I can recognise how to search information, assess and evaluate the information from the emails. Lines and internets that someone sent to me (cite from Chen's interview, 22 January 2016)
Lin (a low SR target student, he made a slight and continuous improvement through intervention)	At an early phase	1. He seldom solved any problems by himself (cite from Lin's classroom teacher interview results, 12 October 2014) 2. He was a trouble maker to disturb other students at my class (cite from Lin's science teacher interview results, 08 October 2014)

(*Continued*)

Continued.

Student	Phase	Interview results from students, classroom teacher and science teacher
		3. I'm afraid of talking my idea. And I can't follow someone step, because I haven't done myself yet (cite from Lin's interview, 11 October 2014)
	At a later phase	1. He wants his family to know his good performance in the CDSSI class (cite from Lin's classroom teacher interview results, 20 January 2016)
		2. He understood how to search useful and related information to respond questions at my biology class (cite from Lin's science teacher's interview, 25 January 2016)
		3. Lin always doubted information from internet/Lines or legend. For example, he highly doubted the reliability of using Earthquake Fish to predict the earthquake (cite from Lin's science teacher's interview, 25 January 2016)
		4. Before, I gave up when I face the difficult; now, I try my best not to give up. I will look for answer when I have no idea after I learn from CDSSI class. For example, I would use different ways to resolve my problem, especially my math question (cite from Lin's interview, 22 January 2016)

Appendix 4. Results of paired-*t*-tests of experimental group students' critical thinking and self-regulation in learning science (*N* = 49).

Variables	Pre vs. Post	*M*	SD	*T*	*p*	*d*
[a]CT total	Pre-test	184.15	20.44	**−3.54****	**.001**	**0.46**
	Post-test	194.25	23.17			
[b]Truth-seeking	Pre-test	23.90	4.44	−.28	.785	0.05
	Post-test	24.15	5.72			
[c]Open-mindedness	Pre-test	28.96	4.07	−.62	.541	0.09
	Post-test	29.31	4.06			
[d]Analyticity	Pre-test	27.02	3.61	−1.62	.113	0.22
	Post-test	27.90	4.35			
[e]Systematicity	Pre-test	24.90	4.01	−1.94	.059	0.34
	Post-test	26.38	4.72			
[f]Self-confidence	Pre-test	26.83	5.69	**−3.23****	**.002**	**0.56**
	Post-test	30.08	6.00			
[g]Inquistiveness	Pre-test	27.50	5.32	**−2.16***	**.036**	**0.31**
	Post-test	29.06	4.84			
[h]Maturity	Pre-test	25.04	3.08	**−4.43*****	**.000**	**0.72**
	Post-test	27.38	3.38			
[i]Self-regulation in learning science total	Pre-test	211.00	27.36	**−2.42***	**.020**	**0.31**
	Post-test	219.19	25.21			
[j]Receiving the information	Pre-test	20.54	3.42	−1.28	.207	0.20
	Post-test	21.23	3.47			
[k]Evaluating the information	Pre-test	30.35	4.30	**−2.81****	**.007**	**0.32**
	Post-test	31.92	5.55			
[l]Triggering change	Pre-test	19.94	2.50	−1.57	.122	0.26
	Post-test	20.63	2.86			
[m]Searching for options	Pre-test	32.75	5.36	**−2.92****	**.005**	**0.42**
	Post-test	34.79	4.30			
[n]Formulating a plan	Pre-test	28.21	4.82	.33	.741	−0.05
	Post-test	27.96	5.38			
[o]Implementing the plan	Pre-test	18.35	3.82	.94	.351	−0.13
	Post-test	17.79	4.51			

(*Continued*)

Continued.

Variables	Pre vs. Post	*M*	SD	*T*	*p*	*d*
[p]Assessing	Pre-test	24.81	4.16	**−4.25*** **	**.000**	**0.62**
	Post-test	27.50	4.58			

[a]Critical thinking total includes 56 items with total ranges from 56 to 280.
[b]Truth-seeking includes 8 items with total ranges from 8 to 40.
[c]Open-mindedness includes 8 items with total ranges from 8 to 40.
[d]Analyticity includes 8 items with total ranges from 8 to 40.
[e]Systematicity includes 8 items with total ranges from 8 to 40.
[f]Self-confidence includes 8 items with total ranges from 8 to 40.
[g]Inquistiveness includes 8 items with total ranges from 8 to 40.
[h]Maturity includes 8 items with total ranges from 8 to 40.
[i]Self-regulation in learning science total includes 63 items with total ranges from 63 to 315.
[j]Evaluating the information includes 9 items with total ranges from 9 to 45.
[k]Triggering change includes 9 items with total ranges from 9 to 45.
[l]Searching for options includes 9 items with total ranges from 9 to 45.
[m]Formulating a Plan includes 9 items with total ranges from 9 to 45.
[o]Implementing the plan includes 9 items with total ranges from 9 to 45.
[p]Assessing includes 9 items with total ranges from 9 to 45; bold numbers indicates a significant difference between the EG and CG.
*$p < .05$.
**$p < .01$.
***$p < .00$.