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IMPROVING PRESERVICE CHEMISTRY TEACHERS' CRITICAL THINKING AND SCIENCE PROCESS SKILLS USING RESEARCH-ORIENTED COLLABORATIVE INQUIRY LEARNING

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Abstract

This research aims to enhance preservice teachers' critical thinking and science process skills using Research-Oriented Collaborative Inquiry Learning (REORCILEA). Sixty-four preservice chemistry teachers attended the General Chemistry course over 8 weeks in an Indonesian public university. In a quasi-experimental design, two intact classes were randomly assigned as the experimental and control groups. The Rubric for Critical Thinking Skills, the Observation Checklist for Science Process Skills, and a semi-structured interview protocol were used as data collection tools. Quantitative data were analyzed using an independent samples *t*-test and paired samples *t*-test, while the results of semi-structured interviews were analyzed using thematic analysis. The results of the *t*-test revealed that the REORCILEA was found more effective than the expository teaching model in fostering students' critical thinking and science process skills. The results of the interviews also indicated that experimental group students had a more positive perception of REORCILEA. Regarding these findings, instructors are recommended to apply the REORCILEA model in order to promote students' critical thinking, science process skills, and motivation to learn in STEM-related courses.

Keywords – Collaborative inquiry learning, Critical thinking skills, Research-oriented approach, Science process skills, General chemistry.

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1. Introduction

Eliciting students' critical thinking and science process skills as a part of transferable skills is the main goal in higher education. Transferable skills, or twenty-first-century skills, have been found important for most students to succeed at university and in the workplace (Aka, Guven & Aydogdu, 2010; Gupta, Burke, Mehta & Greenbowe, 2015; Quattrucci, 2018; Stephenson, Miller & Sadler-McKnight, 2019; Tosun & Taskesenligil, 2013; Weaver, Samoshin, Lewis & Gainer, 2016). A number of empirical studies have also pointed out those two essential skills to share a certain relationship with other variables; e.g., argumentation performance (Lin, 2013), academic achievement (Ghanizadeh, 2016), mathematical reasoning ability (Tee, Leong & Abdul-Rahim, 2018), and scientific creativity (Dikici, Ozdemir & Clark, 2018). Unfortunately, previous evidence informs that both competencies at various levels of education need to be improved (Stephenson et al., 2019; Tosun & Taskesenligil, 2013). Hence, weak critical thinking and science process skills should be developed and evaluated.

Importantly, instructors are in charge of finding an effective teaching method to teach transferable skills. Several non-traditional teaching methods were found to have positive contributions in improving critical thinking (Stephenson et al., 2019; Ku, Ho, Hau & Lai, 2013) and science process skills (Tosun & Taskesenligil, 2013). However, in some cases, a single teaching method (e.g., inquiry-based or problem-based learning) was usually found to be unfavorable to learners with limited experience (Ellis & Gabriel, 2010; Kirschner, Sweller & Clark, 2006). Thus, it is necessary to apply a mixed teaching approach to simultaneously optimize the competency of novice learners. In this study, the researcher proposes the Research-Oriented Collaborative Inquiry Learning (REORCILEA) model to develop preservice chemistry teachers' critical thinking and their science process skills.

The significance of the current study is that REORCILEA provides students with a conducive learning environment that encourages them to discuss, ask questions, test the veracity of information through various sources, and draw conclusions. Thus, it supports the development of creative thinking and collaboration of pre-service teachers. In contrast to most of the previous studies that used single sample data collection, the current study was designed using a mixed methods design. Thus, this study allows researchers to explore and compare results from quantitative and qualitative sources comprehensively. Moreover, the use of mixed teaching methods in chemistry education is rarely explored; thus, this study has the potential to fill a gap in the literature by incorporating theoretical approaches into research-based learning practices in higher education. The current study is expected to be useful for the development of the body of knowledge.

1.1. Literature Review

1.1.1. Research-Oriented Collaborative Inquiry Learning (REORCILEA)

The REORCILEA was developed based on Vygotsky's social development theory. The model integrates the research-oriented approach and collaborative inquiry learning. Nowadays, the research-teaching nexus has become a major activity in higher education. In research-oriented learning (ROL), students are involved in the process of systematic investigation including designing and executing relevant methodological principles (Griffiths, 2004). ROL facilitates students to develop an enthusiasm for critical inquiry and find creative solutions (Guinness, 2012). Whereas in collaborative inquiry learning (CIL), students work in small groups to perform inquiry steps that resemble scientists' activities (i.e., designing experiments, analyzing data, disseminating findings, etc.) to acquire knowledge on scientific processes (Bell, Urhahne, Schanze & Ploetzner, 2010). CIL tasks allow students to explore more about certain concepts, share ideas with peers, and evaluate their own ideas (Gijlers & de Jong, 2009). In short, research and inquiry activities are designed to prepare students to inquire and evaluate knowledge through research-like experiences (Brew, 2012). In this teaching model, various activities in both approaches have been combined. The learning cycle in the REORCILEA includes five sequences of activities; initiating, hypothesizing, experimenting, writing a paper, and evaluating and reflecting (Rohaeti, Prodjosantoso & Irwanto, 2020).

A number of empirical studies focusing on the improvement of student's academic performance have been carried out (Stephenson et al., 2019; Tosun & Taskesenligil, 2013). However, most research only investigated the effectiveness of a single teaching approach; whilst, the use of a mixed teaching approach needs to be also explored (Ku et al., 2013). The combination of the two teaching approaches is believed to create a more favorable learning environment (Kolloffel, Eysink & de Jong, 2011) that facilitates students to be actively engaged in their learning. In addition, this type of learning environment allows instructors to obtain the advantages of a certain single approach that could not be facilitated in other approaches. In this case, the implementation of the REORCILEA within the context of undergraduate research plays an important role in career selection (Brew, 2012).

1.1.2. Critical Thinking (CT)

CT is part of higher-order thinking skills that strongly relate to science education. Ennis (1993) defined CT as a reasonable reflective thinking process focusing on deciding what to believe or what to do. The importance of critical thinking skills has long been recognized among experts. Empirical evidence shows that CT is closely related to creative thinking, self-efficacy, problem-solving skills, and academic achievement (Eggers, Lovelace & Kraft, 2017; Kanbay & Okanli, 2017; Phan, 2009). Students with adequate CT are predicted to make better academic and non-academic achievements. Moreover, they are likely to be hindered from having paranormal and pseudoscientific beliefs (Wilson, 2018). It is obvious that critical thinking is important in modern life, both in academic and daily life contexts (Miri, David & Uri, 2007). Furthermore, CT mastery is often associated with students' decision-making ability in solving real-life problems (Tiruneh, de Cock, Weldeslassie, Elen & Janssen, 2016). Therefore, critical thinking is considered as a fundamental twenty-first century skill that students use to elaborate, question, and develop new thoughts, and decide what to believe through different processes.

This research evaluated students' CT based on their written laboratory reports including universal intellectual values such as accuracy, consistency, clarity, sound evidence, precision, good reasons, relevance, breadth, depth, and fairness (Oliver-Hoyo, 2003; Paul & Elder, 2013). In order to ensure the authenticity, validity, reliability of the information, critical thinkers need to examine various arguments in a written report and evaluate relevant evidence underlying a claim (Vieira & Tenreiro-Vieira, 2014). In short, students need to be engaged in learning experiences that develop their CT (Vieira & Tenreiro-Vieira, 2014). It is due to CT relates to mental processes (i.e., predicting, analyzing, synthesizing, evaluating, and reasoning) which can be improved through inquiry-based instruction (Tiruneh et al., 2016).

1.1.3. Science Process Skills (SPS)

SPS has been recognized as an important part of science learning since half a century ago. SPS is a set of transferable skills that students use to solve problems the way scientists do (Yeany, Yap & Padilla, 1986). These skills consist of basic and integrated process skills. In this research, the basic process skills include observing, measuring, classifying, using numbers, communicating, using space/time relations, inferring, and predicting. The integrated process skills cover formulating hypotheses, defining operationally, experimenting, controlling variables, and interpreting data (American Association for the Advancement of Science - AAAS, 1967; Livermore, 1964). In laboratory activities, basic process skills are the foundation for more complex integrated process skills (Wesley, Krockover & Devito, 1985). In general, science process skills are conceptualized as general procedures that scientists usually use in every stage of their research to construct scientific knowledge and solve unstructured problems.

Previous research believed that SPS cannot be developed only by reading scientific literature (Livermore, 1964), instead, it can be effectively constructed through non-traditional teaching strategies (Wesley et al., 1985). The use of modern learning methods for SPS acquisition has a positive impact on the improvement of students' formal thinking abilities and academic achievement (Padilla, Okey & Dillashaw, 1983; Aka et al., 2010). Students with adequate SPS tend to have better decision-making abilities. This fact indicates that SPS is an important skill needed to solve problems and make decisions. Therefore, promoting SPS through a constructivist learning environment is considered necessary.

1.2. Research Questions

This research investigated the influence of the research-oriented collaborative inquiry learning (REORCILEA) on the critical thinking and science process skills of first-year preservice chemistry teachers. With regard to the aim of this research, the research questions were formulated as follows:

1. Is there any significant improvement in the CT and SPS scores of experimental and control group students after treatment?
2. Is there any significant difference between pretest/posttest CT and SPS scores in both groups?
3. How do students in the experimental group perceive the intervention given?

2. Methodology

2.1. General Background

In order to provide a better understanding of students' critical thinking and science process skills, a mixed-method design was employed. In the current study, a quasi-experimental design with the pretest−posttest control group was used for the purpose of examining the effect of REORCILEA on the critical thinking and science process skills of first-year preservice chemistry teachers. Shadish, Cook, and Campbell (2002) stated that quasi-experimental design involves an intervention in which units are not randomly assigned. Students in the experimental group were instructed using the REORCILEA while the control group learned using the expository teaching method. This research was conducted in 10 sessions over 8 weeks, where students in both groups were taught by a female lecturer in order to avoid instructor bias. All students participated voluntarily in this research.

2.2. Participants

Participants were 64 first-year preservice chemistry teachers (aged 18 to 20) enrolled in the General Chemistry course in a public university in Yogyakarta, the central part of Indonesia. Approximately 90% of participants were female students. In Indonesia, the preservice chemistry teachers program is a four-year program that prepares competent chemistry teachers for the high school level. There were 33 students (3 males and 30 females) in the experimental group and 31 students (3 males and 28 females) in the control group who were randomly selected. After the intervention, nine students in the experimental group who obtained high, moderate, and low posttest scores were invited to attend the interview session. All participants had equal socio-economic and educational backgrounds. They came from low- to middle-income families.

2.3. Instruments

2.3.1. The Oliver-Hoyo Rubric for Critical Thinking (OHRCT)

The OHRCT consisting of six traits was developed by Oliver-Hoyo (2003) to evaluate students' critical thinking skills based on their written laboratory reports. The rubric was modified and translated into Indonesian based on feedback from 4 experts in chemistry education and assessment. All traits included the writing of the abstract, organization of the paper, sources of information used, the content of the paper, the relevance of the ideas, and clarity of the written presentation. Each trait used a 5-point Likert scale in which a score of "5" indicated the fulfillment of all evaluation criteria and "1" showed that no criteria were fulfilled at all. The minimum and maximum scores were 6 and 30 respectively. The coefficient of Cronbach's alpha reliability was calculated at 0.84.

2.3.2. The Observation Checklist for Science Process Skills (OCSPS)

The OCSPS was designed by Irwanto, Rohaeti and Prodjosantoso (2018) to measure students' science process skills based on their laboratory work. The observation checklist consisted of nine sub-skills; observing, measuring, inferring, communicating, formulating hypotheses, identifying variables, designing an investigation, experimenting, and interpreting data. Each sub-skills consisted of 2 items using a 4-point Likert scale where a score of "4" showed highly observed and "1" for unobserved. The highest score referred to students' advanced skills in performing their lab work. There were a total of 8 items to assess basic process skills and 10 items to measure integrated process skills. All items were constructed according to relevant literature (e.g., Livermore, 1964; Ostlund, 1992; Padilla, 1990). The minimum and maximum scores were 18 and 72 respectively. The OCSPS was reviewed for face and content validity by 13 senior lecturers and then tested on 176 students in the pilot study. The value of Cronbach's alpha reliability was found at 0.88.

2.3.3. Semi-Structured Interviews (SSI)

Semi-structured interviews focusing on preservice teachers' opinions about chemistry teaching using the REORCILEA were carried out individually. The interviews were conducted to investigate students' reasons regarding the efficacy of the teaching model in eliciting their critical thinking and science process skills. During the interview, each student was asked four questions and each interview lasted around 25 min. After that, the data obtained from the interviews which were recorded using an audio recorder were transcribed verbatim. All questions were developed by the researcher and then validated by two professors in chemistry education. Some questions were; *What are the strengths of the REORCILEA? How do you think about chemistry before and after the lecture? What do you do during the instructions?* and *Do the learning activities designed in REORCILEA improve your CT and SPS?*

2.4. Procedures

Data collection was done after receiving written permission from the Head of the Department of Chemistry Education. This research was also approved by the academic institution's Institutional Review Board (IRB). At the beginning of the instruction, the OHRCT and OCSPS were administered in the pretest to both experimental and control groups. Those instruments identified students' initial skills. Then the two groups received different treatments by the same female instructor. Both groups had two 50 min laboratory sessions and three 45 min courses per week during the 2018/2019 academic year. The topics included reaction rates, acids and bases, and colligative properties. At the end of the intervention, the OHRCT and OCSPS were administered in the posttest. After that, one-third of the students in the experimental group were randomly selected through stratified sampling for interviews to explore their perceptions about the REORCILEA and to investigate their learning motivation.

2.4.1. The Intervention in the Experimental Group

Students in the experimental group were taught using the REORCILEA; a student-centered learning model consisting of five phases; initiating, hypothesizing, experimenting, writing a paper, and evaluating and reflecting. At the beginning of the lecture, the instructor distributed laboratory worksheets to guide students in designing their own experiments and collecting data. Students were then assigned to search relevant scientific journal articles from the internet.

Initiating phase. Students were given ill-structured problems and stimulated to solve these problems. In order to find solutions, students reviewed relevant research articles to enrich their insights and information. The results of the scientific literature review, especially related to methods and findings were then employed to plan and design an experiment. *Hypothesizing phase*. Students submitted various questions and claims related to possible solutions based on previous scientific evidence that they obtained. Working in groups, students exchanged opinions with peers and their instructor, responded to arguments, and reflected on ideas in order to formulate hypotheses. *Experimenting phase*. Students in small groups (4-5 students) worked like scientists in the laboratory to conduct experimental procedures as designed in the previous phases. In order to test their hypotheses, students analyzed, explored, found, solved problems, and disseminated the data. *Writing phase*. Students collected, organized, interpreted, and presented their data accurately in the form of tables, graphs, or diagrams with good narration. Afterward, group members wrote a scientific paper that presented various theories and relevant research findings to both support and contradict the results of their experiment. *Evaluating and reflecting phase*. Each group presented arguments, ideas, and findings in the classroom. Students evaluated their performance during learning activities. Self-evaluation was also done to encourage students to be more active in assessing their understanding and improve their performance to a more satisfactory level. The results of the evaluation were seen as feedback for students to enhance their work and learning process in the future.

2.4.2. The Intervention in the Control Group

Students in the control group were instructed on the same topic using the expository teaching method. In the classroom, the instructor employed the lecture-discussion method and then instructed the students to read the general chemistry textbook as the main learning source to be memorized. The instructor then challenged the students with some questions to be solved individually. At the end of the lecture, the instructor summarized all sub-topics and instructed students to take notes. During laboratory activities, students worked in small groups (4-5 students) to complete experiments on related topics using the cook-book method in which they followed step-by-step procedures to answer research questions. Finally, students wrote a laboratory report individually to be submitted.

2.5. Data Analysis

Descriptive statistical analysis was employed to analyze quantitative data. Paired samples *t*-test was performed to explain the significant increase in the pretest to posttest scores in each group. Then, independent samples *t*-test was executed to compare the significant differences in the pretest and posttest scores on the CT and SPS of students in the experimental and control groups. Before performing a parametric statistic test, the Kolmogorov-Smirnov test had been employed to ensure the normality of the data. The results of the assumption test showed that the pretest and posttest scores were normally distributed ($p > 0.05$). A significance level was set at 0.05 using SPSS 25. In addition, the effect size, a measure of the effectiveness of an intervention is categorized as follows; small ($d = 0.20$), medium ($d = 0.50$), and large ($d = 0.80$). A thematic analysis (Braun & Clarke, 2006) was used to analyze the results of the semi-structured interviews to support the quantitative data.

3. Results

3.1. The Effect on Students' Critical Thinking Skills (CTS)

Students' CTS scores were evaluated from their written reports based on the assessment rubric. The paired samples *t*-test compared the pretest and posttest mean scores in each group. The comparison revealed whether the increase in CTS scores of students in the experimental group was statistically significant. The results of the analysis are illustrated in Table 1.

According to Table 1, students' posttest scores ($M = 25.727$; $SD = 1.682$) in the experimental group were significantly higher than their pretest scores ($M = 17.424$; $SD = 1.659$). Although the students' posttest scores ($M = 22.516$; $SD = 1.998$) in the control group were also significantly higher than their pretest scores ($M = 17.032$; $SD = 1.941$), the mean CTS scores of the experimental group were higher at 3.211. The experimental group students were more dominant in acquiring the CTS compared to the control group. This result confirmed that the REORCILEA model has a greater effect in promoting students' CTS [$t(32) = -20.398$; $p = 0.001$) than expository teaching.

In order to answer whether the REORCILEA model was effective in improving students' CTS, the independent samples *t*-test was performed. Generally, the results can be seen in Table 2.

Groups		n	Mean	SD	t	p
Experimental	Pretest	33	17.424	1.659	-20.398	0.001
	Posttest	33	25.727	1.682		
Control	Pretest	31	17.032	1.941	-11.231	0.001
	Posttest	31	22.516	1.998		

Table 1. The Comparison Between Pretest and Posttest Scores on CTS (Paired *t*-Test)

	Groups	n	Mean	SD	t	p
Pretest	Experimental	33	17.424	1.659	0.870	0.387
	Control	31	17.032	1.941		
Posttest	Experimental	33	25.727	1.682	6.971	0.001
	Control	31	22.516	1.998		

Table 2. The Comparison Between Pretest and Posttest Scores on CTS (Independent *t*-Test)

Based on Table 2, there was no statistically significant difference in the pretest mean scores between experimental and control group students [$t(62) = 0.870$; $p = 0.387$]. It indicated that students in both groups had equal initial skills before the treatment. At the end of the lecture, there was a statistically significant difference in the posttest mean CTS scores between the experimental and control groups in favor of experimental group students [$t(62) = 6.971$; $p = 0.001$]. It can be understood that the essential skills of students in the experimental group have improved compared to the control group after the treatment. This finding is supported by the high effect size ($d = 1.74$), which indicates that the instruction is effective in developing students' CTS.

3.2. The Effect on Students' Science Process Skills (SPS)

Paired samples *t*-test was executed to reveal whether improvement in the mean SPS scores obtained by the experimental group was statistically significant. In general, the results of the test are illustrated in Table 3.

Table 3 indicates that students' posttest scores ($M = 31.424$; $SD = 0.902$) of the experimental group are significantly greater than their pretest scores ($M = 25.864$; $SD = 1.048$). Although the students' posttest scores ($M = 29.048$; $SD = 1.660$) in the control group were found significantly greater than their pretest scores ($M = 25.936$; $SD = 1.662$), the posttest mean SPS scores obtained by the experimental group students was higher at 2.376 compared to those who were taught using traditional instruction. Therefore, the REORCILEA has been found more effective in eliciting students' SPS [$t(32) = -22.179$; $p = 0.001$).

To investigate whether the REORCILEA model is effective in increasing students' SPS, the independent samples *t*-test was performed. The results of the test are shown in Table 4.

As presented in Table 4, there was no significantly significant difference in the pretest mean scores between experimental and control group students in terms of SPS [$t(62) = -0.205$; $p = 0.838$]. This finding indicates that students had equal initial skills before the treatment. On the other hand, a significantly significant difference in the posttest scores between experimental and control group students was found, in which the experimental group obtained a higher one [$t(62) = 7.050$; $p = 0.001$]. This finding implies that the vital skills of students in the experimental group have improved compared to prior intervention. In addition, the effect size was also found large ($d = 1.76$), indicating a strong relationship between the learning model and students' SPS.

Groups		n	Mean	SD	t	p
Experimental	Pretest	33	25.864	1.048	-22.179	0.001
	Posttest	33	31.424	0.902		
Control	Pretest	31	25.936	1.662	-9.120	0.001
	Posttest	31	29.048	1.660		

Table 3. The Comparison Between Pretest and Posttest Scores on SPS (Paired *t*-Test)

	Groups	N	Mean	SD	t	p
Pretest	Experimental	33	25.864	1.048	-0.205	0.838
	Control	31	25.936	1.662		
Posttest	Experimental	33	31.424	0.902	7.050	0.001
	Control	31	29.048	1.660		

Table 4. The Comparison Between Pretest and Posttest Scores on SPS (Independent *t*-Test)

3.3. Students' Perceptions of REORCILEA

This section presents students' responses and views on activities before, during, and after lectures using REORCILEA. The quantitative findings are supported by the results of interviews conducted after the treatment in which students shared their positive changes, ideas, and perceptions as follows.

"*Before carrying out the experiment, I read the journal articles first which references had me think critically. Also, I designed and did experiments that improved my scientific skills, such as observing, collecting data, assembling the equipment, and* *using laboratory equipment. After the experiment, I re-read the papers before processing the data to draw conclusions based on the evidence.” [EG2]*

“In my opinion, laboratory activities positively affected my critical thinking skills because all students were required to make an experimental design and conduct our own experiment. Students observed and identified some data carefully. After the experiment, we analyzed the data. So, laboratory activities have been very useful.” [EG5]

“Experiments allowed me to think more critically about why something can happen, especially in the context of chemistry. I analyzed why an error in an experiment can occur, why a chemical reaction can produce sediment, about a change in color, and so forth. Conducting an experiment made me think logically and objectively based on the obtained data. Thus, my scientific skills were also enhanced.” [EG8]

These opinions indicate that the experimental group students have more positive perceptions of REORCILEA. In summary, intervention in the experimental group motivates students to learn, both prior and subsequent lectures. The treatment provided to the experimental group students has succeeded in increasing their critical thinking and science process skills to a satisfactory level.

4. Discussion

This research successfully investigated the effect of the REORCILEA model on the CT and SPS of preservice chemistry teachers compared to the traditional teaching approach. Before the treatment, students’ pretest mean scores of both experimental and control groups were unsatisfactory. After instruction, a significant increase occurred in the mean scores of students’ CT and SPS from pretest to posttest in both groups. However, the experimental group scored better than the control group in the two dependent variables. Similarly, the results of the paired samples *t*-test also showed a significant increase in students’ CT and SPS after being engaged in collaborative inquiry learning. Parallel with previous research (e.g., Gupta et al., 2015; Goeden, Kurtz, Quitadamo & Thomas, 2015), this research successfully confirmed that the REORCILEA model is useful in developing students’ skills in their General Chemistry course.

In line with the results of the independent samples *t*-test, it was found that there were statistically differences in posttest mean scores in the two groups in favor of experimental group students. It indicated that CT and SPS of the experimental group students were significantly improved compared with those of the comparison group students. The results of the semi-structured interviews also confirmed that the experimental group students were likely to have more positive perspectives about chemistry learning after the treatment. This result implies that the REORCILEA did not only contribute to the development of students’ essential skills, but it also enhanced students’ learning motivation, evaluated the learning process, and brought a positive future career. The results are consistent with the previous studies (e.g., Winkelmann, Baloga, Marcinkowski, Giannoulis, Anquandah & Cohen, 2014; Weaver et al., 2016) which also revealed that collaborative inquiry activities progressively promoted students’ CT and SPS.

Based on the results of the interviews, REORCILEA motivated students to learn and offered them an opportunity to be more engaged in their own learning. Increased motivation among students may be due to REORCILEA creating a situation that allows students to seek information from various sources and collaborate with teachers and peers. Such a learning environment is believed to increase students' collaboration, creativity, and deep thinking, all of which lead to increased motivation (Barron & Darling-Hammond, 2010). In addition, this teaching method encourages students to draw different conclusions, form new understandings, and think deeper to solve real-world problems (Kriewaldt, Robertson, Ziebell, Di Biase & Clarke, 2021). Thus, students are more interested in and enjoy lessons in a REORCILEA setting, and in turn, increase their motivation and engagement.

The effectiveness of the REORCILEA in enhancing students’ performance also comes from the systematic and simultaneous teaching and learning activities designed in each phase. In the initiating phase, students are exposed to ill-structured problems and stimulated to find solutions. In order to find feasible solutions, students need to review the most relevant research articles that will broaden their knowledge and information resources. The results of this scientific literature review, especially the ones about the research methods and findings, will be employed to plan and design their experiment. It is generally accepted that exposure toward academic articles develops students' content mastery which would also improve their critical appraisal skills (Botelho, Lo, Bridges, McGrath & Yiu, 2013). At the same time, through problem-solving, teaching and learning activities become more effective in improving students' critical thinking skills (Quattrucci, 2018). In a systematic review, Wilder (2015) also asserted that students who are exposed to non-routine problems tend to have stronger critical thinking and science process skills.

This finding also supports the view proposed by Hamann, Pollock and Wilson (2012) that small group discussion is an interactive method that brings students to experience learning satisfaction and better critical thinking skills. In this study, students raise various questions and claims related to the possible solutions that they propose based on the previously collected empirical evidence in the hypothesizing phase. In small group discussions, students exchange their ideas and arguments collaboratively with their peers, while the instructor responds to their opinions and reflects their ideas to formulate a certain hypothesis. Hypothesizing is believed to be a vital process in inquiry learning as expressed by Gijlers and de Jong (2005). Furthermore, students work in a group to design experimental procedures based on scientific methods. In this phase, students determine the dependent and independent variables, identify the relationship between variables, and investigate the possible factors influencing the variables. Previous studies have revealed that learning in a small group is more fun and effective in promoting learning achievements compared to the use of traditional lecturing (Jarjoura, Tayeh & Zgheib, 2015). Thus, a collaborative learning environment positively contributes to the enhancement of students' performance in the current research.

In a study, group work has been known as a way to cultivate students' critical thinking skills (Fung & Howe, 2014). In fact, Loes and Pascarella (2017) also associated the positive impact of collaborative learning activities with first-year students' critical thinking skills. For instance, students in small groups act like scientists. During laboratory work, they perform experimental-based activities. To test their hypotheses, students analyze, explore, find and solve problems, and collaboratively communicate the obtained data. As emphasized by Wu and Hsieh (2006), inquiry learning facilitates students to identify causal relationships, use data as evidence, describe reasoning processes, build explanations, and evaluate evidence. It provides various learning opportunities while at the same time develops students' science process skills. Several other studies even reported that inquiry-based instruction activates students' science process skills and problem-solving skills, improves their learning achievement and retention, and makes a positive predictor for students' science-career aspirations (Kang & Keinonen, 2017). Therefore, experiments were assumed to be able to enhance critical thinking and science process skills. For these reasons, the current research claims that the benefits of the REORCILEA highly develop students' critical thinking and scientific skills when compared to students in the control group.

5. Conclusion and Limitations

In conclusion, this research revealed that the use of REORCILEA has successfully improved the CT and SPS of preservice chemistry teachers than the traditional teaching method. The transferable skills of experimental group students were significantly superior to those of the control group students. Students also expressed positive attitudes toward the learning process using the REORCILEA. As a suggestion, if educators wish to abridge research and teaching in higher education, they should adopt a collaborative inquiry-based learning approach that would progressively develop students' critical thinking and scientific skills (Spronken-Smith & Walker, 2010; Walkington, Griffin, Keys-Mathews, Metoyer, Miller, Baker et al., 2011). It is important for instructors to implement the REORCILEA in order to catalyze students' learning while at the same time increasing their performance in the General Chemistry course.

This research suffered from some limitations. The first limitation was related to the use of a limited sample size. In this research, only preservice chemistry teachers in two classes at an Indonesian public university were involved. Thus, future research is encouraged to involve larger samples. The second limitation is related to time constraints which only allowed this research to be conducted within an 8-week period which was relatively short to evaluate the effectiveness of a new instructional model. Additionally, this research is focused on developing students' transferable skills, so future studies can investigate the impact of the REORCILEA on the affective and cognitive domains to gain more comprehensive findings. Furthermore, the researcher recommends future research to compare the effectiveness of the REORCILEA model to other constructivist teaching approaches.

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