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Research Article

Using of claim, evidence, and reasoning strategy in scientific explanation and argumentative writing skills of grade nine chemistry students

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Claim, evidence, and reasoning is an innovative instructional approach to writing scientific explanations and argument, which are essential aspects of scientific inquiry and science education. Though constructing scientific explanations and arguments can be challenging for students of all ages, explicit implementation of the claim, evidence, and reasoning strategy can improve students' conceptual understanding and scientific writing skills. Consequently, the study was conducted to investigate the effect of claim, evidence, and reasoning strategy on students' conceptual understanding and scientific writing skills in Chemistry lessons. It also explored students' perceptions of using the claim, evidence, and reasoning strategy in Chemistry instructions. The study administered a convergent parallel mixed method and a quasi-experimental design. The quantitative data were collected using an achievement test, scientific writing assessment score, and survey questionnaire. The quantitative data were analyzed with a descriptive statistics, and the achievement test was further analyzed with an inferential *t*-test (independent and paired sample *t*-test) to validate the variation of scores between the experimental and control groups. The qualitative data obtained from document analysis and semi-structured interviews were analyzed using rubrics and thematic analysis. Then, the data were triangulated and interpreted to validate the findings. The statistical analysis of achievement tests and scientific writing scores has shown significant improvement in the mean difference of the students who were intervened using the claim, evidence, and reasoning strategy. Therefore, the present study has revealed that the claim, evidence, and reasoning strategy is an effective instructional approach to enhance academic achievement and scientific writing skills (scientific explanations and arguments) in Chemistry instructions.

Keywords: Argument and chemistry, Claim, Explanation, Evidence, Perception, Reasoning

1. Introduction

Science education is an integral aspect of modern society, playing a vital role in the economic prosperity and development of countries like Bhutan. Bhutanese science education emerged alongside modern-based education in the 1960s, with a curriculum initially borrowed from India (Childs et al., 2012). Nevertheless, in 1986, the borrowed curriculum was replaced with the implementation of the New Approach to Primary Education [NAPE], to promote scientific inquiry within Bhutan's social and environmental contexts (Royal Education Council [REC], 2012). Further reforms in 1999 and 2000 led to the integration of three science disciplines for grades VII and VIII into a unified Integrated Science curriculum. The integrated science helped the educators overcome time limitations and improved the Bhutanese-based curriculum from primary to grade VIII (REC, 2012).

Since its inception, the Bhutanese science curriculum has undergone numerous reforms and adaptations to meet the rapidly changing needs of society. The most recent reform, launched in 2019, reflects the shift from traditional, silo-based approaches to integrative Science, Technology, Engineering, and Mathematics [STEM] education. The National School Curriculum [NSC]—Science Curriculum Framework (PP–XII) was restructured within this STEM educational approach to strengthen the content and practice of 21st-century skills augmented with several key competencies. Within the broad goal of STEM-based science education, we see two emphases emerging: (1) Develop and apply the skills of scientific inquiry in understanding how scientists work; and how scientific knowledge is constructed and accepted by the scientific community, and (2) Make students 'scientifically literate' and be able to participate in critical and informed debates on the key questions and issues that may affect their own lives, community, country, and the world at large (Department of Curriculum and Professional Development [DCPD], 2021, p. 3-4).

With the implementation of the NSCF, teachers are required to explore innovative instructional strategies that encourages students learn 'how' and 'why' rather than memorizing facts and figure. This shift is intended to arm students with transversal competencies and 21st-century skills essential for dynamic participation in the global community. Furthermore, several research (e.g., Driver et al., 2000; McNeill et al., 2006; McNeill & Krajcik, 2008) has supported scientific practices of constructing scientific explanations and arguments as an essential aspect of scientific inquiry and, therefore, science education.

However, in the Bhutanese context, teachers receive minimal or no explicit training on how to teach students to write scientific explanations and arguments. The essential process skills (e.g., engaging in argumentation and constructing scientific explanations) are not taught as separate skills (DCPD, 2021). Brindle et al. (2016) reported a similar situation in the study that their college teacher preparation programs provided no or minimal instruction on teaching to write. Similarly, the pre-service teachers are not adequately trained in argumentative writing, preventing them from effectively implementing these practices in their classrooms. Despite the attempt made by the MoE to prepare Bhutanese teachers for 21st-century transformative pedagogy through initiatives such as 'English for Effective Communication,' traditional instructional approaches in classrooms remain predominantly content-focused. Consequently, these methods do not adequately support the development of essential scientific practices, such as writing scientific explanations and arguments.

Although the latest Bhutanese NSCF outlines instructional strategies to foster scientific writing, reasoning, and argumentation through scientific processes, little research has been conducted on their implementation. Among these strategies, the claim, evidence, and reasoning [CER] framework has been recognized as an effective method for constructing scientific explanations and arguments. Previous studies (e.g., Becker, 2014; Long, 2014; Samosa, 2021; Traut, 2017) have demonstrated the effectiveness of CER across various grade levels and disciplines, showing that it enables students to construct better scientific explanations and arguments. CER, a subject-specific strategy introduced in the latest NSCF, is an instructional approach designed to help students structure scientific explanations and arguments (McNeill & Krajcik, 2008). The CER framework is based on the principle that students generate evidence through inquiry-based activities, which in turn serves as the foundation for their explanations of scientific phenomena (Berland & Reiser, 2009). It consists of three components: (1) a claim, which is a statement or answer to a question or problem; (2) evidence, which consists of scientific data used to support the claim; and (3) reasoning, which connects the claim to the evidence and explains why the data qualify as supporting evidence (McNeill, 2011; McNeill & Krajcik, 2008). Research has shown that integrating CER into curriculum materials, instructional strategies, and assessments improves students' conceptual understanding, scientific thinking, and communication skills (McNeill & Krajcik, 2011).

Therefore, owing to the limited research on CER implementation in the Bhutanese context, this study aims to investigate the impact of the CER strategy on students' conceptual understanding and scientific writing skills in chemistry. By exploring how CER influences students' ability to construct scientific explanations and arguments, this study seeks to provide empirical evidence supporting the integration of CER into Bhutanese science classrooms. Furthermore, findings from this study may offer valuable insights into how professional development initiatives and instructional strategies can be enhanced to foster scientific literacy and inquiry-based learning in Bhutan.

2. Literature Review

2.1. Claim, Evidence, and Reasoning Strategy

Concept of CER Strategy is an innovative instructional approach to writing a scientific argument and explanations that are designed to help "students improve their ability to justify their written claims by engaging in inquiry practice" (McNeill & Krajcik, 2008). The CER framework was developed by Katherine McNeill of Boston College and Joseph Krajcik of Michigan State in response to the National Science Education Standards (National Research Council [NRC], 1996) and to help students improve their ability to construct explanations for scientific phenomena.

McNeill and Krajcik's (2008) creation of the CER framework was influenced by the work of Toulmin (1958), who was a British philosopher and educator. Toulmin (1958) investigated moral reasoning and logic, which served as the cornerstone of Toulmin's Model of Argument (Jackson & Schneider, 2018). According to Gabriel et al. (2020), Toulmin's Model of Argument identified six components of a compelling argument: the claim, the grounds, the warrant, the supporting evidence, the rebuttal, and the qualifiers (Metaxas et al., 2016). The term 'claim' refers to the conclusion to a problem; 'grounds' refers to the evidence that supports the claim; 'warrants' refers to assumptions and scientific principles that are accepted as true; 'backing' refers to the principles that support the warrant; 'rebuttal' refers to a refutation of another person's views or claims; and 'qualifier' refers to the evidence that supports a true claim (Ahmed & Sharaf, 2019).

McNeill and Krajcik (2008) adopted Toulmin's Model of Argument to design a CER framework to improve scientific explanation and argumentation skills and support students as they construct knowledge about scientific phenomena (Fox, 2020). The three essential components of the framework are (1) claim— "an assertion or conclusion that answers the original question;" (2) evidence— "scientific data that supports the claim;" and (3) reasoning— "a justification that shows why the data count as evidence to support the claim" (McNeill et al., 2006, p.158). An ideal argument for students to hone their argumentation skills includes a claim, two pieces of evidence, and reasoning (McNeill et al., 2006). Claims are expected first because it is the direct answer to a question, while the evidence and reasoning provide the support (McNeill & Krajcik, 2011). Claims are believed to be the easiest part of the argument for students (McNeill & Krajcik, 2011); however, Sadler (2004) demonstrated that students could struggle with articulating and defending claims.

Alegado and Lewis (2018) described the evidence as data obtained through experiments and classroom activities or as content-related facts from various sources. Data become evidence when tied to a claim intended to address a question on a scientific phenomenon (Jackson et al., 2016). Evidence can be represented textually, visually, or numerically in documents or through investigative processes (Whithaus, 2012). A claim's credibility can be gauged by how well it is supported by data. The reasoning process is a crucial step in the CER framework. The reasoning justifies a claim with appropriate and sufficient principles showing how data represents evidence (Blank et al., 2016). Reasoning also connects the claim and evidence, which correlates the two making a claim believable (Bugarcic et al., 2014). According to Yearwood and Stranieri (2010), reasoning is interconnected with an individual rationale based on the premise of selected principles and goals. The reasoning process demonstrates an individual's understanding of scientific phenomena. However, the fourth component, rebuttal, can be added in middle school as students develop more knowledge and expertise with the framework. The rebuttal presents an alternate assertion, counter-evidence, and counter-reasoning for why it is unacceptable (McNeill & Martin, 2011). Therefore, CER framework strengthens ability to construct scientific explanations, critical thinking and problem-solving skills essential for scientific literacy. By systematically integrating claims, evidence, and reasoning, students learn to engage in meaningful discourse and develop a deeper understanding of scientific concepts.

2.2. Impact of CER Strategy on Conceptual Understanding and Scientific Writing Skills

Over the past years, several studies have demonstrated the effectiveness of using scientific argumentation instruction to improve students' conceptual understanding and scientific argumentative writing skills in many courses and grade levels. The construction of scientific explanations and engaging in the argumentation process are essential components of scientific inquiry (Berland & Reiser, 2009; Driver et al., 2000). Ponce de leon (2025) stated that conceptual understanding encompasses the ability to apply ideas to scientific situations, reason through core ideas, predict the behavior of science systems, solve science problems, and translate concepts across different science scales and representations. Students indirectly enhance their conceptual understanding by developing scientific explanations, often the result of the reasoning component or an additional assessment in CER (Mcneil, 2011).

For instance, Cetin (2014), in his study to examine the effect of explicit argumentation instruction using Toulmin's Argument Pattern to facilitate conceptual understanding and argumentation skills of general chemistry preservice first-grade science teachers using non-equivalent control group design from a public university in Turkey concluded that the intervention based on argumentation positively affected students' understanding of reaction rate concepts. Experimental group's mean score improved considerably more than the Control group's mean score over the course period, although both groups improved significantly after the intervention. Moreover, the consideration of specific reaction rate concepts in constructing an argument revealed that the percentages of students using accurate scientific knowledge increased in both the experimental and control groups. Nevertheless, the increase in the experimental group was higher than for the control group.

A more recent study by Samosa (2021) claimed that the implementation of CER results is a significant improvement in students' scientific argumentative writing skills in biology teaching after the intervention, which was statistically significant. Further, Samosa (2021) asserted that while extensive and complex, the CER strategy promises to build both argumentative writing skills and the students' science content knowledge. Additionally, a Malaysian study implemented CER in a Chemistry classroom to explain data about chemical neutralization reactions and the students improved their reasoning skills and their content knowledge (Heng et al., 2015). Further, the study by Novak and Treagust (2018) posited that students require the ability to make claims based on available evidence and then use scientific concepts to demonstrate why the evidence supports the claim to improve their scientific writing and academic performance.

A similar study by Short et al. (2020) found that discussion through the CER framework was beneficial to students learning and comprehension of concepts and improved scientific literacy skills in statistically significant ways when applied effectively. In addition, it has been shown that when guided by the CER framework, scientific discourse in the classroom increased high-level thinking about the content, and students made more profound connections within the material (Short et al., 2020). This is because the CER framework can support students in productive classroom discussions and science writing as it gives a structure to communicate and justify their ideas (McNeill & Martin, 2011). Moreover, the CER framework is seen as a strategy that can enhance students' ability to analyze evidence and back up their claims, enhance their scientific understanding, and increase their reasoning and communication skills (McNeill & Krajcik, 2011). Additionally, the CER framework is considered a tool to support writing in science and help students nurture their conceptual understanding of science by allowing them the opportunity to justify their scientific claims (Zembal-Saul et al., 2013).

These literatures demonstrate that CER strategy is effective in enhancing students conceptual and argumentative writing across various disciplines (Cetin, 2014; Heng et al., 2015; Novak & Treagust, 2018; Samosa, 2021). However, few studies have explored its effectiveness specifically in chemistry. Additionally, prior studies often measure general improvements without a detailed analysis of how each CER component contributes to learning.

2.3. Students' Perception of the Impact of CER Strategy

The use of CER framework was instrumental in improving the attitude of students in an introductory college level Chemistry course during three in-class Chemistry activities involving gas laws, solubility, and buffers during the semester-long course (Atkinson, 2018). This study found that allowing more time in class for CER activities led to increased student engagement, understanding of Chemistry concepts, and improved scientific explanations. Further, Cetin (2014) stated that more than half of the research participants in his study were enthusiastic during the argumentation activities. The majority of students also believe that the only time they need to write is in English class; math/science classes do not require them to write about the topic or subject (Abid, 2020). Similarly, Long (2014) examined the effects of the CER writing strategy on the teaching and learning of science in eighth grade and found that at the end of the intervention period, overall positive attitudes about science increased from 52% to 63%, an 11% increase. Moreover, interviewees responded that CER activities were more fun, and more outgoing stuff, making more sense to them. Similarly, the study conducted by Traut (2017) with grade nine students concluded that students' confidence in the ability to support a claim with evidence shifted towards feeling more comfortable using evidence in their conclusion writing after the treatment period as compared to the pre-treatment period. While research highlights the positive influence of CER on students' engagement and attitudes toward science (Atkinson, 2018; Long, 2014; Traut, 2017), there is limited empirical evidence on how students perceive the strategy in chemistry classrooms. The existing literature generalize students' attitude across multiple discipline, making it unclear whether chemistry -specific challenges impact perception differently. Additionally, most research relies on self-reported surveys without triangulating findings with performance data.

2.4. Challenges Faced by Students in Using the CER Strategy

Although the CER strategy improves conceptual understanding and the construction of scientific explanations, research shows that these practices are challenging for most students and adults. Students often struggle with reasoning, particularly explaining why selected evidence supports their claim, even when they can link claims to evidence. For instance, Loch (2017) found that reasoning was the most challenging aspect for 27% of surveyed students, while Traut (2017) noted students found claims and evidence more straightforward. Similarly, studies revealed that only a small percentage of students successfully incorporated all three components of the CER framework, with many failing to connect evidence to claims or select appropriate evidence (Ruiz-Primo et al., 2008). Students also face challenges in defining and providing sufficient evidence, often relying on opinions rather than scientific data, or using inadequate evidence due to difficulties in understanding information or subject matter. Additionally, English language learners [ELLs] experience further challenges due to language barriers, which can hinder their ability to construct CER statements effectively (Fox, 2020; Kennedy & Folkes, 2018). This study contributes to the existing literature by identifying chemistry-specific obstacles students encounter in CER-based learning and exploring instructional strategies to enhance their ability to construct well-supported scientific statement.

2.5. CER in Bhutan

The literature on CER framework in Bhutan is relatively limited, given that the approach is still emerging as instruction strategy in Science Education. As of now, there are no large-scale studies being conducted to assess CER's impact in Bhutanese classroom. This study aims to address the research gap by investigating CER's potential to improve conceptual understanding and scientific writing in Bhutan's unique cultural and educational environment. By integrating the CER framework into science lessons, this research contributes to understanding how structured argumentation strategies can foster critical thinking, enhance communication skills, and develop scientific reasoning in Bhutanese students.

Therefore, this research had the following questions:

RQ 1) Is there a significant difference between the academic achievement and scientific explanation and argumentative writing skills of EG and CG in terms of pre-test and post-test scores?

RQ 2) What are students' perceptions toward teaching and learning of Chemistry lessons using the CER strategy?

RQ 3) What challenges do students face in using the CER strategy in learning Chemistry concepts?

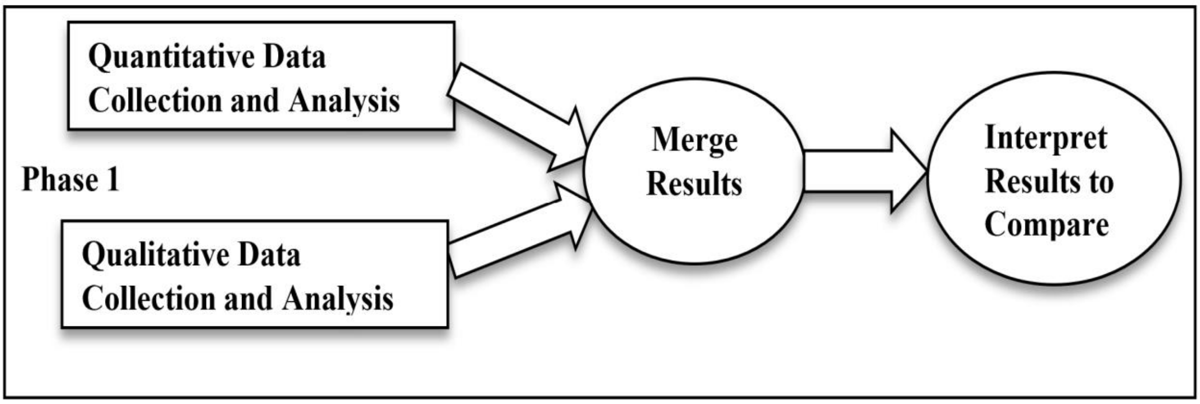
The findings of this study were expected to serve as baseline data to inform teachers and other relevant stakeholders about the impact of CER strategy as a means of intervention in enhancing students' conceptual understanding and scientific writing skills. The result also provides the perception of students on CER framework as an intervention tool. The challenges on CER implementation were highlighted to provide insights into areas that require support, enabling educators and policymakers to develop strategies to address these issues effectively and ensure the successful integration of the CER framework into science education.

3. Method

3.1. Research Design

This study used convergent parallel mixed-methods design, in which quantitative and qualitative data were collected concurrently and independently analyzed, and the results were compared and interpreted in the same phase (one-phase design) of the research process (Creswell & Creswell, 2018). Quantitative data from pre- and post-tests, surveys, and statistical analyses helped measure the effectiveness of CER in improving conceptual understanding and writing performance. In contrast, qualitative data from interviews and document analysis captured students' perceptions, challenges, and depth of learning. Combining both types of data enable a comprehensive understanding of the CER strategy's impact on students' scientific explanation and argumentative writing skills. Moreover, the direct comparison of two data sets provides the researchers with a "convergence" of data sources (Creswell, 2014). The research process for this study is given in Figure 1 where two sets of data were obtained, analyzed separately, and compared.

Figure 1
Convergent Parallel Mixed Methods Design (One–Phase Design)



Note. Adapted from Creswell and Creswell (2018).

3.2. Sample

The study was conducted in one of the Middle Secondary Schools under Pemagatshel district in Bhutan. The location of the study was selected based on the researcher's convenience. The target population for this study was grade IX students comprising two sections. The researcher used convenience sampling for choosing one of the Middle Secondary Schools under Pemagatshel district, while a non-probability purposive sampling procedure was employed to form the study's Experiment Group [EG] and Control Group [CG]. The study investigated the effectiveness of the CER strategy in scientific explanation and argumentative writing skills of grade IX students. The identified section of an EG and CG had students of mixed learning abilities. The mixed learning abilities of students were identified within the groups by administering a pretest. This baseline data informed the analysis of CER strategy impact across varying skill levels, providing a more nuanced and contextually relevant interpretation of results

In addition, six students were selected using stratified random sampling for a semi-structured face-to-face interview based on their academic performance to collect the qualitative data. Likewise, random sampling was used to select written artefacts of the EG students for the document analysis.

3.3. Instrument

In this study, a pre-Rate of Reaction Concept Test [RORCT] and pre-intervention writing assessment [WA] were administered to compare whether EG and CG participants had the same conceptual understanding abilities and scientific writing skills before intervention. Similarly, a post-RORCT and post-intervention writing assessment was conducted to evaluate whether the intervention impacted students' scientific writing skills and conceptual understanding at the end of the experiment responding to researchers' first and fourth questions. RORCT and writing assessment questions were framed based on the topic 'Rate of Reaction' from chapter five, grade IX Chemistry. RORCT incorporated almost 70% of Competency-Based Questions [CBQ], whereas writing assessment questions were 100% CBQ to assess students' scientific argumentative writing skills and conceptual understanding of reaction rate. The rubric adapted from (Traut, 2017) was used to score the writing assessment.

The quantitative data related to the second research question was gathered through a closed-ended students' opinion survey questionnaire [SOSQ], which was framed and partially adapted from Loch (2017). It used a five-point Likert scale with the following responses: Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree and with corresponding values of 5 to 1 to measure EG participants' perception of CER strategy in learning Chemistry and scientific argumentative writing skills. Survey questionnaires were based on the six major themes; interest, satisfaction, understanding, confidence, and ability to use three CER components in their scientific writing. Moreover, responses to open-ended survey questions at the end of SOSQ answered the third research question.

The qualitative data were collected using semi-structured interviews, document analysis, and open-ended questionnaires. The study employed semi-structured interviews to explore students' perceptions of the CER strategy in enhancing scientific argumentative writing skills and in-depth conceptual understanding of the topic after the intervention. Further, the documents such as Chemistry notebooks, class test answer scripts, practical records, journals, and project write-ups were used for document analysis to determine the effectiveness of the intervention on EG. Moreover, one open-ended question at the end of SOSQ was used to determine students' challenges in using the CER strategy to understand the Chemistry concept and construct scientific explanations and arguments. Such instruments helped the researcher triangulate the data and validate the findings.

3.4. Intervention in Experimental Group and Control Group

3.4.1. Experimental group

The intervention happened over three weeks, each with 3-4 50-minute periods. In the 1st week of the intervention, the researcher explicitly introduced the CER strategy through a PowerPoint presentation and direct instruction on the CER strategy used by McNeill and Krajcik (2011) and a CER template using non-science examples followed by science examples using prompt-based CER activities to help students formulate their explanations and arguments. For instance, the teacher showed short video clips of an Audi car commercial where a little girl claims her father is a space alien. After watching the video, students were asked to answer the following question prompts, who is my dad? Next, students came up with evidence and reasoning for why it may be considered that her dad is an alien. Finally, their arguments were summarized and discussed in class to demonstrate a compelling argument and set an example. In this intervention phase, students were oriented on CER rubrics adapted from Traut (2017) and the CER template.

Moreover, a copy of the CER rubrics, template, and a sample of CER science writing was made accessible through the class information board to remind students about the CER assessment and basic CER information. In the second and third weeks of the intervention period, the participants were taught the 'Rate of Reaction' concept using the CER strategy and scaffolded to do lab conclusion write-ups, class assignments, and homework using the CER framework based on the experiment conducted to study the effect of factors affecting the rate of reaction. The treatment in the EG indicated the effectiveness of CER strategy in teaching Chemistry concepts and argumentative writing skills. Moreover, the differences between pre-and post-concept tests and scientific writing assessment scores indicated the CER's significance in enhancing argumentative writing skills and conceptual understanding in Chemistry. Finally, a semi-structured interview was conducted to collect data from six students to compare the effectiveness and perceptions of students towards the explicit instruction of the CER strategy.

Table 1
Data Collections Tools

	Experimental group (EG)	*Control group (CG)*
Pre-data	RORCT1 and WA1	RORCT1 and WA1
Intervention	CER	TLM
Post-data	RORCT2, WA2, SOSQ, and SI	RORCT2 and WA2

Note. RORCT1 and RORCT2: Pre-test and Post-test of Rate of Reaction Concept; WA1and WA2: Pre- and post-intervention writing Assessment; SI: Semi-Structured Interview; SOSQ: Students Opinion Survey Questionnaire; CER: Claim, Evidence, and Reasoning strategy; and TLM: Traditional Lecture Method.

3.4.2. Control group

A control group is essential to many research designs, allowing the researcher to minimize the effect of all variables except the independent variable. The control group, receiving no intervention, was used as a baseline to compare groups and assess the intervention's effect. The control group was taught the same topic through the traditional lecture method (teacher-centered) for the same duration as the experimental group.

3.5. Reliability and Validity of the Instruments

In educational research, the reliability and validity of the tools are of great concern. So, to ensure more authentic and reliable tools, a pilot test on the SOSQ was conducted at one of the schools in southern Bhutan. The results were generated in SPSS 25; the overall Cronbach Alpha was 0.938, which indicates a good degree of internal consistency. In addition, validation of SOSQ, RORCT, and writing assessment questions were done by principal supervisors. Furthermore, survey questionnaires to evaluate students' perception of CER were partially adapted from Samosa (2021) and Loch (2017) to increase the validity of the instrument.

3.6. Data Analysis

Quantitative data were analyzed using Statistical Package for Social Science version 25. Similarly, the qualitative data were transcribed and analyzed based on the approaches of Creswell's thematic coding technique (Creswell, 2014). The document analysis was done using the rubrics adapted from Traut (2017).

3.6.1. Rate of reaction concept test and writing assessment

A comparative statistical analysis using paired sample t-test was performed within the group that analysed the pre- and post-data of the experimental and control groups. The pre-and post-data of the two groups were compared by conducting an independent sample t-test to evaluate and compare the learning achievement and scientific argumentative writing skills of the participant exposed to CER strategy and traditional lecture methods. The inferential statistic *t*-test with $p < .05$ level of significance, mean, and standard deviation was used to conclude the results.

3.6.2. Students opinion survey questionnaire

The data analysis on SOSQ towards CER was analysed using SPSS 25. The mean and standard deviation from the survey questionnaires was used to determine the level of students' interest, satisfaction, understanding of the concepts, thinking skills, confidence, and ability to use three components of CERs effects on learning Chemistry concept and scientific argumentative writing skills using Browns model to interpret the perception level.

3.6.3. Semi-structured interview

The semi-structured interview allows respondents the freedom to express their views on their terms. The interview data were transcribed and coded to examine students' perceptions of using CER to teach the rate of reaction concept and construct scientific explanations and arguments. Creswell (2014) describes a systematic process for coding data in which specific statements are analyzed and categorized into themes. This process typically begins with reading through the transcripts several times to gain a complete understanding of the data. Initial codes, representing concepts, are assigned to segments of text. These codes are then grouped into broader, overarching themes that represent recurring patterns and significant meanings within the data. This iterative process of coding and theme development allows for a structured and in-depth analysis of the qualitative data, ultimately revealing students' perceptions of the CER strategy.

3.6.4. Document analysis

According to Bowen (2009), document analysis helps researchers collect qualitative data from the topics and statistical records of interest under study. In this study, written artefacts (e.g., Chemistry notebooks, class test answer scripts, practical records, journals, and project write-ups) of EG students were collected and scored using CER rubrics adapted from Traut (2017) to determine the effectiveness of the CER strategy before and after the intervention.

4. Results

4.1. Analysis of Achievement Tests and Scientific Writing Assessment Scores of EG and CG using Independent Sample *t*-test

An independent sample *t*-test was run to compare the variability of scores in pre- and post-data from the concept test and writing assessment scores between EG and CG. Table 2 and 3 illustrates the statistical result of the independent sample t-test of pre- and post-data between EG and CG.

Table 2
Independent Sample t-Test of Pre-test and Pre-writing Assessment Scores between Groups

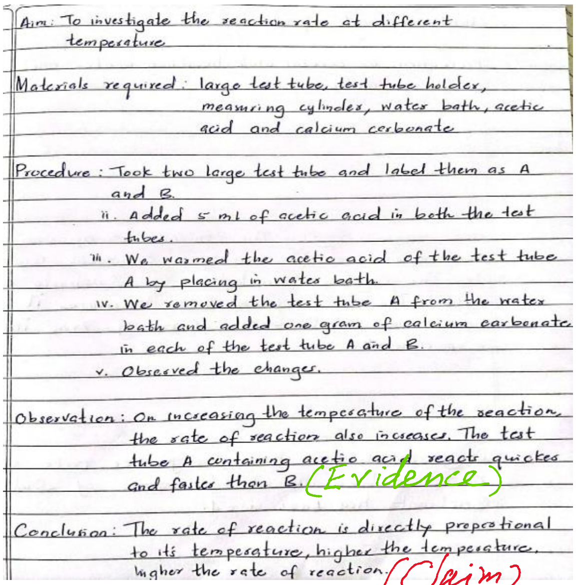
	Groups	*N*	*Mean*	*Mean difference*	*SD*	*t*	*df*	*p*
Pre-test	CG	31	7.94	0.33	2.33	0.58	59	.567
	EG	30	8.27		2.14			
Pre-writing assessment score	CG	31	6.97	1.23	4.74	1.11	59	.269
	EG	30	8.20		3.83			

An independent sample *t*-test was conducted to determine whether there is a difference in pre-RORCT scores between CG and EG. The results indicated a non-significant difference in pre-RORCT score between CG (M = 7.94, SD = 2.33) and EG (M = 8.27, SD = 2.15); $t(59)$ =.58, $p > .05$. The magnitude of the differences in the means (mean difference = 0.33, 95% CI: 1.48 to .82) was very small. Similarly, the results of an independent sample *t*-test conducted to compare the pre-writing assessment scores for CG and EG showed no statistically significant differences between the two groups (M = 6.97, SD = 4.74, and M = 8.20, SD = 3.83; $t(59)$ = 1.11, $p > .05$). The magnitude of the differences in the means (mean difference = 1.23, 95% CI: 3.44 to .98) was very small, indicating that the distribution of students between CG and EG was equally considered in terms of learning abilities and scientific writing skills before the intervention (see Table 2).

Correspondingly, document analysis performed on six randomly sampled students' Chemistry practical records and test papers of EG before the intervention revealed that though a clear and scientifically sound claim was implied, it was supported by insufficient and irrelevant evidence with or without reasoning, as shown in Figure 2 and 3 indicating that students were unaware of the three components of scientific explanations to be incorporated into scientific writing.

Figure 2

Students' Lab Conclusion Write-up Before the Intervention



Aim: To investigate the reaction rate at different temperature.

Materials required: large test tube, test tube holder, measuring cylinder, water bath, acetic acid and calcium carbonate

Procedure: Took two large test tube and label them as A and B.
ii. Added 5 ml of acetic acid in both the test tubes.
iii. We warmed the acetic acid of the test tube A by placing in water bath.
iv. We removed the test tube A from the water bath and added one gram of calcium carbonate in each of the test tube A and B.
v. Observed the changes.

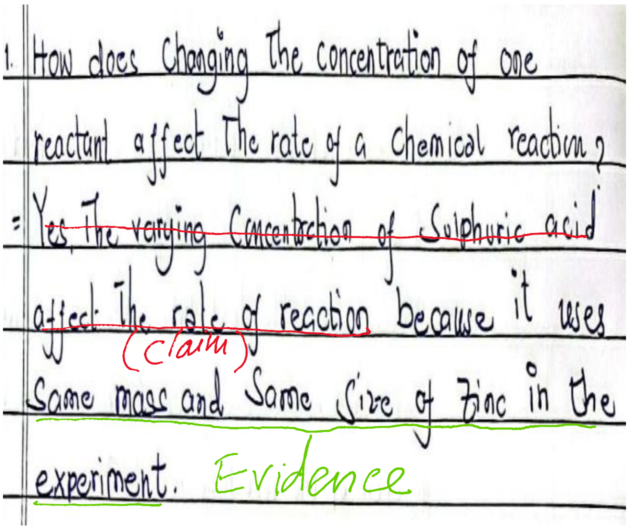
Observation: On increasing the temperature of the reaction, the rate of reaction also increases. The test tube A containing acetic acid react quicker and faster than B. (Evidence)

Conclusion: The rate of reaction is directly propotional to its temperature, higher the temperature, higher the rate of reaction. (Claim)

Claim is clear and scientifically sound and directly related to question
Evidence is appropriate and may be sufficient
Reasoning: No reasoning

Figure 3

Response from Pre-writing Assessment Task



1. How does Changing The concentration of one reactant affect The rate of a Chemical reaction?
: Yes. The varying Concentration of Sulphuric acid affect The rate of reaction because it uses Same mass and Same Size of Zinc in the experiment. Evidence
(claim)

Claim is clear and scientifically sound and directly related to question
Evidence is appropriate and not sufficient
Reasoning: No reasoning

Table 3

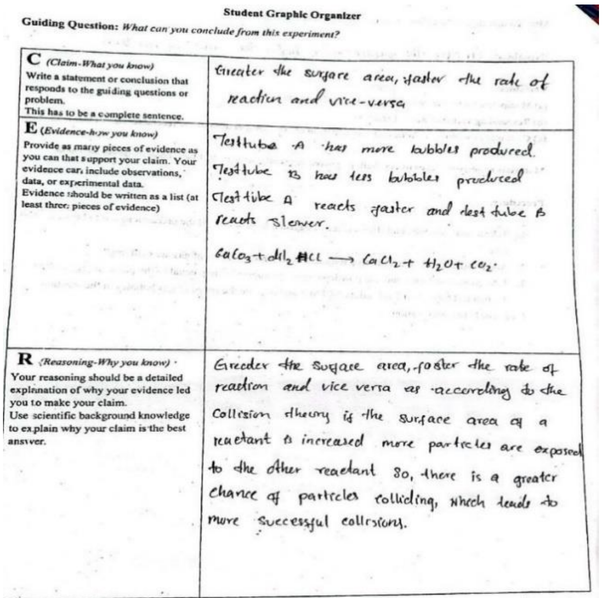
Independent Sample t-Test of Post-test and Post-writing Assessment Scores between Groups

	Groups	*N*	*Mean*	*Mean difference*	*SD*	*t*	*df*	*p*
Pre-test	CG	31	11.26	3.51	3.56	4.15	59	<.001
	EG	30	14.77		3.01			
Pre-writing assessment score	CG	31	14.55	12.99	6.82	4.64	59	<.001
	EG	30	27.53		13.80			

Further, to examine the prevalence of any statistically significant difference between the post-test and post-writing assessment scores of EG and CG, an independent sample t-test was run at a 95% confidence interval. There were significant differences (t(59) = 4.15, p < .001) in the test scores with the mean score for EG (M = 14.77, SD = 3.01) was higher than CG (M = 11.26, SD = 3.56). The magnitude of the differences in the means (mean difference = 3.51, 95% CI: 5.20 to 1.82) was significant. Similarly, an independent sample t-test was run to compare the post-intervention writing assessment score for CG and EG. There were significant differences (t(59) = 4.64, p < .001) in the post-writing assessment score with the mean score for EG (M=27.53, SD=13.80) was nearly double the mean score of CG (M=14.55, SD=6.82). The magnitude of the differences in the means (mean difference= 12.99, 95% CI: 18.64 to 7.33) was very high, indicating the effectiveness of the CER strategy over the traditional lecture method in enhancing conceptual understanding and scientific argumentative writing skills (see Table 3).

Correspondingly, document analysis performed on six randomly sampled practical records and test papers of the experimental group following the intervention has shown a well-structured scientific lab conclusion write-up using a CER graphic organizer. The lab conclusion write-up shows a compelling claim with appropriate and sufficient evidence in which reasoning uses appropriate scientific principles and evidence is linked to the claim, as shown in Figures 4 and 5.

Figure 4
Students' Lab conclusion Write-up After the Intervention



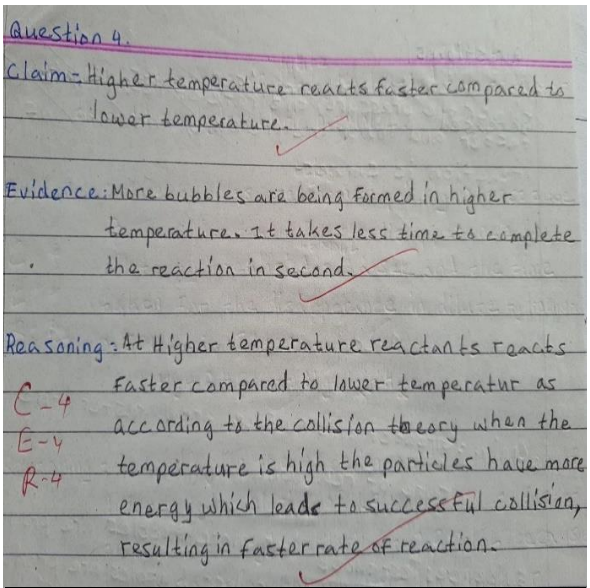
Student Graphic Organizer

Guiding Question: *What can you conclude from this experiment?*

C *(Claim-What you know)* Write a statement or conclusion that responds to the guiding questions or problem. This has to be a complete sentence.	Greater the surface area, faster the rate of reaction and vice-versa
E *(Evidence-how you know)* Provide as many pieces of evidence as you can that support your claim. Your evidence can include observations, data, or experimental data. Evidence should be written as a list (at least three pieces of evidence)	Testtube A has more bubbles produced. Test tube B has less bubbles produced. Test tube A reacts faster and test tube B reacts slower. $CaCO_3 + dil_2 HCl \longrightarrow CaCl_2 + H_2O + CO_2$
R *(Reasoning-Why you know)* Your reasoning should be a detailed explanation of why your evidence led you to make your claim. Use scientific background knowledge to explain why your claim is the best answer.	Greater the surface area, faster the rate of reaction and vice versa as according to the Collision theory if the surface area of a reactant is increased more particles are exposed to the other reactant so, there is a greater chance of particles colliding, which leads to more successful collisions.

Student has demonstrated well-structured scientific lab conclusion write-up with three components of CER

Figure 5
Response from Post-writing Assessment



Question 4.
Claim- Higher temperature reacts faster compared to lower temperature.
Evidence: More bubbles are being formed in higher temperature. It takes less time to complete the reaction in second.
Reasoning: At Higher temperature reactants reacts faster compared to lower temperatur as according to the collision theory when the temperature is high the particles have more energy which leads to successful collision, resulting in faster rate of reaction.
C-4
E-4
R-4

Three components of CER are evident in students' response to competency based question for writing assessment task.

4.2. Pretest and Post-test Data within the Groups

The paired sample *t*-test was performed to determine the significant difference between pre-data and post-data (Conceptual test and Writing assessment scores) within EG and CG. Table 4 and 5 shows the result of paired sample t-tests between the pre-data and post-data of CG and EG, respectively.

Table 4
Paired Sample t-Test of Control Group (CG)

Groups	*N*	*Mean*	*Mean difference*	*SD*	*t*	*df*	*p*
Pre-test CG	31	7.94	3.32	2.34	5.52	30	<.001
Post-test CG	31	11.26		3.56			
Pre-WA score CG	31	6.97	7.58	4.74	8.30	30	<.001
Post-WA score CG	31	14.55		6.82			

The result of paired sample t-test between the pre-test and post-test of CG showed that there were significant differences ($t(30) = 5.52$, $p < .001$) in test scores with the mean score for post-test (M=11.26, SD=3.56) was higher than pre-test ($M = 7.94$, $SD = 2.34$). The magnitude of the differences in the means (mean difference = 3.32, 95% CI: 4.55 to 2.09) was significant. Similarly, paired sample t-test between the pre-writing and post-writing assessment scores of CG revealed that there were statistically significant differences ($t(30) = 8.29$, $p < .001$) in the writing assessment score with the mean score for post-writing assessment (M = 14.55, SD = 6.82) was more than double the score of pre-writing assessment (M = 6.97, SD = 4.74). The magnitude of the differences in the means (mean difference= 7.58, 95% CI: 9.45 to 5.71) was significant, indicating that the traditional lecture method was also found to be effective in enhancing the conceptual understanding and scientific argumentative writing skills of secondary level Chemistry students (see Table 4).

Table 5

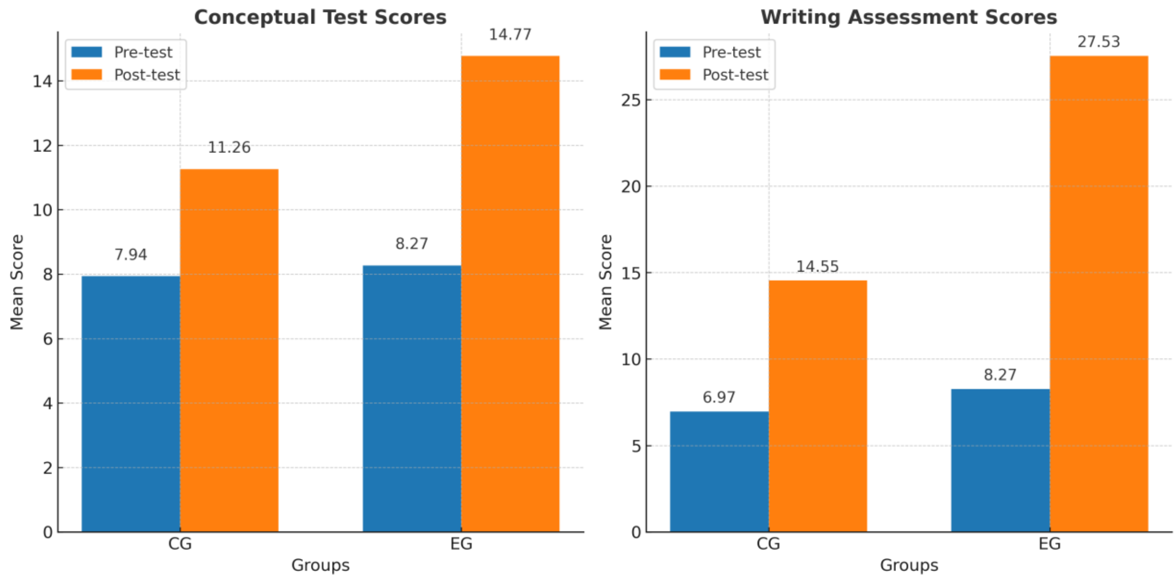
Paired Sample t-Test of Experimental Group (EG)

Groups	*N*	*Mean*	*Mean difference*	*SD*	*t*	*df*	*p*
Pre-test EG	30	8.27	6.50	2.15	13.57	29	<.001
Post-test EG	30	14.77		3.01			
Pre-WA Score of EG	30	8.20	19.33	3.83	7.81	29	<.001
Post-WA Score of EG	30	27.53		13.80			

Similarly, the result of paired sample t-test between the pre-test and post-test of EG showed that there was a significant increase in the mean test score during post-test (M = 14.77, SD = 3.01) than pre-test (M = 8.27, SD = 2.15); $t(29) = 13.57$, $p < .001$. The magnitude of the differences in the means (mean difference= 6.50, 95% CI: 7.48 to 5.52) was significant. Likewise, paired sample t-test between the pre-writing and post-writing assessment scores of EG revealed that there was a statistically significant difference ($t(29) = 7.81$, $p < .001$) in the writing assessment score with the mean score for post-writing assessment (M = 27.53, SD = 13.80) was more than triple the pre-writing assessment (M = 8.20, SD = 3.83). The magnitude of the differences in the means (mean difference = 19.33, 95% CI: 24.40 to 14.27) was very high. Thus, the higher mean score of EG (M = 4.77) and (M = 27.53) as compared to CG (M = 11.26) and (M = 14.55) in post-test and post-writing assessment scores, respectively, has revealed that the students who were intervened through CER strategy outperformed the students taught using lecture method (see Table 5) and (see Figure 6).

Figure 6

Overall Results of Pre- and Post-Data within and between the Groups



4.3. Students' Perception of CER Strategy in Chemistry Instruction

In this study, perception refers to students' opinions towards the use of CER strategy in learning the chemistry concept and in scientific writing skills. The analysis of students' perception of CER strategy in chemistry instruction possesses a high level of perception with an overall (M = 4.19; SD = 0.72). The descriptive findings were interpreted by referring to a range of mean values and their cross-ponding level of perception designed by the Brown Model (2010) (The level of perception is categorized as Highest (4.51–5.00, Strongly Agree), High (3.51–4.50, Agree), Moderate (2.51–3.50, Neutral), Low (1.51–2.50, Disagree), and Lowest (1.00–1.50, Strongly Disagree). In addition, Pearson's Correlation tests was run to determine the prevalence of any association between variables (interest, satisfaction, understanding, thinking skills, confidence, and components of CER as independent variables and students' RORCT and Scientific writing Assessment score as dependent variables).

The descriptive analysis of the survey questionnaire was interpreted and triangulated with the major themes generated from the semi-structured interview, as listed below.

Table 6
Result of Students' perception in Learning Rate of Reaction Using CER Strategy

Themes	*N*	*Mean*	*SD*	*Perception level*
Interest	30	4.38	0.73	High
Satisfaction	30	4.37	0.74	High
Conceptual understanding	30	4.27	0.72	High
Thinking skills	30	*4.51*	*0.51*	Highest
Confidence	30	3.67	0.78	High
Components of CER strategy	30	3.95	0.83	High
Overall	30	4.19	0.72	High

4.3.1. Interest

The interest in the context of this study refers to the feeling of students in wanting to know or learn more about the Rate of Reaction using the CER strategy. As shown in Table 6, survey data analysis of the theme ‘interest’ revealed highly positive perspectives of the students with an overall (M = 4.38; SD = 0.73), indicating that students showed a high level of interest in learning the Rate of Reaction concept taught through CER strategy.

Correspondingly, most students in their interview expressed that the CER strategy heightened their interest in learning the Rate of Reaction concept because posing a guiding question/problem makes students curious and open-minded to explore answers to the questions or stated problems.

For instance, S1 expressed that:

> In the class, when the teacher poses a guiding question/problem such as ‘How does varying the concentration of one of the reactants affect the Rate of Reaction?’ we become curious to respond to the question. So, as per the CER strategy, first, we provided a claim to the guiding question as a team in the assigned group, followed by gathering evidence to support the claim through an investigation where we had hands-on activity to collect experimental data from the laboratory and observing the effects with our own eyes was so much fun and is my favorite part of the activity as it keeps us engaged throughout the lesson.

Further, most students also stated that CER is one of the innovative pedagogies that helped them become active and engaging learners. For example, S2 stated that:

> The use of CER strategy requires active involvement of us to understand the concept. For example, after providing a claim to the given question, we need to gather evidence to support our claim through investigation or using secondary data (facts from the textbook or other reference books). While doing so, it was exciting and engaging, and I also observed that all group members enjoyed and had fun learning the Rate of Reaction concept.

Further echoed by S4, “When a lesson is taught using the CER strategy, most learning happens through activity-based learning, practically proving things to support the given claim and then connecting the claim and evidence with the reasoning”. These findings indicated that the CER strategy significantly enhanced student interest and engagement in learning the Rate of Reaction concept through its structured, inquiry-based approach.

4.3.2. Satisfaction

In the context of this study, satisfaction refers to how contented students feel when the Rate of Reaction concept is taught using CER Strategy. As shown in Table 6, the analysis of the survey data under the theme ‘satisfaction’ acquired a high perception level (*M* = 4.37; *SD* = 0.74), indicating that students showed a high level of satisfaction with the learning Rate of Reaction concept taught using the CER strategy.

Consistently, students in their interviews expressed that they were satisfied and motivated to learn the Rate of Reaction taught using the CER strategy. S4 stated that:

> I felt motivated and satisfied after learning the new concept through the Claim Evidence and Reasoning (CER) strategy, as it helped me understand the reaction rate with clarity. Additionally, I was interested in the lessons because of the exciting and engaging learning activities conducted in our collaborative group.

On the same note, S6 stated:

> When the teacher engages us using the CER strategy, I gain a deeper understanding of that particular concept because, to address the question fully, we must first look for sufficient evidence to back up the claim and then connect the claim with evidence using scientific principles and theories. So, I felt active throughout the lessons thanks to these learning activities.

4.3.3. Conceptual understanding

The conceptual understanding in this study refers to a deeper understanding of the Rate of Reaction concept and the ability to transfer the knowledge to a real-life situation when the lesson is taught using the CER strategy. As shown in Table 6, analysis of the survey data under the theme ‘Conceptual Understanding ‘resulted a high perception level with an overall (M=4.27; SD=0.72), indicating that students have a positive attitude towards understanding Rate of Reaction concept using CER as an instructional approach.

Similarly, all the interview respondents stated that the CER strategy helped them easily understand the Rate of Reaction. For instance, S3 expressed:

> To answer the guiding questions, this strategy requires us to gather evidence to support the claim through lab investigation, or it may be from books or articles; so, in our cases, we have collected evidence to support our claim through experimental observations. Therefore, whatever we did to compile evidence to support the claim kept us engaged and improved our retention of the concept.

Further, most of the participants in the interview revealed that CER helped them to understand the Rate of Reaction concept easily because they can connect the concept learned in theory with that of practical learning. S2 stated:

> The CER strategy made it easier for me to relate what I had learned in class about the Rate of Reaction concept to practical application because anything we know in theory can be confirmed by the observations, we made from laboratory experiments. Given that each explanation must have three components to make sense, I believe that CER helps connect theory and observation from the laboratory experiment.

4.3.4. Thinking skills

In the context of this study, thinking skills refer to how the use of the CER strategy has stimulated students' thinking skills and helped in understanding the concept of Rate of Reaction. As shown in Table 6, analysis of the survey data under the theme ‘Thinking Skills’ acquired the highest average mean amongst the six themes with (*M* = 4.51; *SD* = 0.51), indicating that the use of CER strategy enhanced the thinking skills of the learners to understand the Chemistry concept.

Congruently, all the interviewees expressed that CER is an innovative teaching-learning approach that improves their ability to think and communicate more scientifically by carefully analyzing evidence and backing up their claims. For instance, S3 stated that:

> When we are doing group activities, it gets me to think more critically and interact and communicate with the other group members, especially when we talk about what evidence to use and what not to use. In addition, CER teaches us how to think and write scientifically, which is helpful when writing lab reports after the experiment.

Likewise, S1 stated that:

> CER is one strategy that helps us organize our thoughts before responding to any questions or problems. It is one of the innovative strategies that enable me to promote critical thinking skills while verifying the evidence from different sources to support the claim. Moreover, it helped me be thorough with scientific principles to give well-grounded reasons to connect claims and evidence to provide a well-structured explanation.

4.3.5. Confidence

The confidence in this study refers to students feeling or belief that they can write lab conclusion write up using three components of the CER strategy. As shown in Table 6, analysis of the survey data under the theme 'confidence' acquired a high average (M = 3.67; SD = 0.78), indicating that students are confident to use three components of CER strategy in the lab conclusion write-up.

However, in their interviews, students had a mixed opinions about their confidence in using CER to construct scientific conclusions. For instance, S3 expressed that:

> Yes, the CER strategy helps me to write a scientific explanation in an organized way, and it was most helpful while writing lab conclusions because we can write what we have understood from our experiment in an organized way, such as what (claim), how (evidence) and why (reasoning). So, in this way, I found that CER helps structure our scientific explanation in an organized way and helps us know what, why, and when it's happening in detail.

Further, S4 stated:

> Compared to the pre-intervention, I now feel very confident in my ability to write a scientific conclusion, especially the lab conclusion write-up, because we did a lot in this chapter. So, having practiced writing a scientific conclusion using the CER strategy, I feel confident in my ability to support a claim with evidence. However initially, I had difficulty linking the claim with evidence, but after knowing the theory that explains the factors affecting the Rate of Reaction, it is much easier to justify my claim backed up with collision theory.

However, 2 out of 6 interviewees expressed that they have experienced difficulties incorporating the third component of CER framework, i.e., reasoning. For instance, S6 stated that,

"Although I am aware of what constitutes a structured scientific conclusion, I am not that confident in using reasoning components as it requires us to be well-versed in scientific principles and theory." Further echoed by S1, 'Using reasoning that relates evidence to my claim is not easy'. These perspectives suggest that while CER strategy generally boosts confidence, clearly linking evidence to their claims, while sound reasoning remains a persistent area requiring further attention and pedagogical support.

4.3.6. Component of CER strategy

In the context of this study, the component of the CER strategy refers to the demonstration of students' ability to incorporate three components of CER strategy in the scientific explanation and argument specifically in the lab conclusion write-up. As shown in Table 7, analysis of the survey data under the theme 'Components of CER' revealed highly positive perspectives on their ability to write three components of CER in the scientific investigation with an overall (M = 3.95; SD = 0.83), indicating the ability of students to incorporate three components of CER strategy in scientific lab conclusion write-up.

Correspondingly, most of the student interviewees have expressed that they were able to include almost 2-3 components of CER in their lab conclusion report. For instance, S4 reported that:

> The use of the CER strategy helped me to write a scientific explanation in a well-organized way. For example, whenever a question is asked, we know that our answer or explanation should have all three components: claim, evidence, and reasoning. And now, I feel that if one component of CER is missing in my answer, it looks like it is half-answered or incomplete. So, I think that CER helps us to give a well-organized explanation/lab conclusion write-up since it demands the presence of all these three components to make sense of our answer.

Overall, the statistical results of the mean value of all themes were above 3.51, which was considered a 'high' degree of perception according to Brown's model (2010).

Table 7
Pearson's Correlation between level of students' perception and Post data (Test Score and Writing Assessment Score)

	Post-test Scores		*Post-WA Score*	
Themes	*R*	*p*	*R*	*p*
Interest	.871**.	<.001	.860**	<.001
Satisfaction	.806**	<.001	.866**	<.001
Conceptual Understanding	.827**	<.001	.815**	<.001
Thinking skills	.850**	<.001	.856**	<.001
Confidence	.803**	<.001	.735**	<.001
Component of CER Strategy	. 920**	<.001	.874**	<.001
Overall	.841**	<.001	0.834**	<.001

Table 7 presents Pearson's correlation coefficients (R) and their associated p-values, demonstrating significant relationships between students' perceptions and their post-test scores and writing assessment scores. Across all themes—interest, satisfaction, conceptual understanding, thinking skills, confidence, component of CER strategy, and overall—strong positive correlations were observed between students' perceptions and both post-test scores (R ranging from .803 to .886) and post-writing assessment scores (R ranging from .735 to .920). The *p*-values for all correlations were less than .001, indicating statistical significance at the 0.01 level (2-tailed). These findings suggest that students' positive perceptions of the learning experience were strongly associated with improved academic performance as measured by both objective tests and writing assessments.

4.4. Challenges faced by Students in Constructing Scientific Explanations and Arguments using the CER Strategy

Students' responses to an open-ended question in the opinion survey questionnaire sheet were compiled and analyzed using thematic coding. The question was, "What problems or difficulties do you experience while the Rate of Reaction is taught using Claim Evidence and Reasoning (CER) strategy in your classes?". The overall responses to this question were focused more on challenges experienced by students in writing scientific explanations and arguments. Consequently, 27 out of (30) students from the EG have responded that of the three components of CER strategy used in constructing scientific explanation and argument with regards to any guiding question prompts, they face difficulty in reasoning components both in verbal and in writing. For example, S26 stated that "writing reasoning that connects my evidence to the claim is difficult." Similarly, S16 stated that "writing reasoning is difficult because we have to know about the scientific principles and laws about the concept learnt." Moreover, students have also expressed their challenges encountered while writing the second component of the CER strategy. For instance, S7 stated that "I face difficulties in providing evidence during the construction of scientific explanations and arguments because I am not sure which is considered good evidence and how much evidence to be listed to support my claim". Further, 15(30) students have mentioned the inability to express themselves in English as another factor that prevents them from constructing well-structured scientific explanations and arguments, indicating that language is another factor that impedes students' construction of scientific explanations and arguments even though the scientific writing framework is at hand.

Correspondingly, the student's confidence level analysis of item 6 'It is difficult to use reasoning that relates my evidence to my claim' has shown a high mean score of (M=4.03, SD= 0.93). In line with the survey findings, the document analysis of students' Chemistry notebooks, project work, and anecdotal notes revealed that the students' overall rubrics score of the reasoning component was low as compared to the scores of the other two components, indicating that students face difficulty in reasoning part as they lack knowledge of scientific principles and theories to give well-grounded reasons.

5. Discussion

The findings of the study were analyzed and discussed under three major themes. The first theme presented both descriptive and inferential findings derived from concept tests and scientific writing assessment scores, comparing traditional teaching methods with the CER strategy as an innovative pedagogical approach to evaluate their relative effectiveness. The second theme discusses students' perception of teaching and learning Chemistry through the CER strategy. The third theme provides a critical analysis of the challenges students encounter in applying the CER strategy to understand Chemistry concepts and develop scientific writing skills. Accordingly, the discussion of findings is structured sequentially in alignment with the research questions.

5.1. Impact of CER Strategy on Academic Achievement and Scientific Writing Assessment Scores

The result of the independent sample *t*-test of RORCT scores between EG and CG has revealed a higher mean difference and a statistically significant result in the post-test compared to the pre-test. Similarly, the paired sample *t*-test within the EG showed a greater improvement from pre-test to post-test compared to the CG.

Correspondingly, the independent sample *t*-test of scientific writing assessments scores between EG and CG found a significantly higher mean difference and statistically significant result in the post-writing assessment score as compared to the pre-writing assessment score. Further, the paired sample *t*-test of the EG exhibited a higher mean difference between pre-writing and post-writing assessment scores with as compared to CG. The finding suggests that the CER strategy is one of the innovative instructional approach teachers can use to enhance the conceptual understanding and scientific argumentative writing skills of 9th-grade Chemistry students. These results are consistent with numerous researches on science education conducted at all grade levels, from middle school to undergraduate, and in the fields of Biology, Chemistry, Physics, and science education classes. Explicit instruction in scientific explanations and arguments has enhanced conceptual understanding and higher quality written scientific explanations and arguments (Abid, 2020; Becker, 2014; Bell & Linn, 2000; Cetin, 2014; Long, 2014; McNeill & Krajcik, 2008).

The analysis of the Quasi-experimental data of the current study revealed statistically significant differences between EG and CG in terms of their concept test and scientific writing assessment scores. More specifically, in EG, students actively participated in the construction of knowledge through the interaction of learning material and peers in a group activity under the teacher's guidance, which helped in the understanding of the concept and helped them apply what they had learned to various contexts. Thus, based on how students responded and performed in pre-post tests and writing assessment scores, it may be argued that the CER strategy as the intervention was the genuine cause and not by chance. Coincidently, the finding of this study agreed with the learning theory of Vygotsky (1978) that learning is facilitated by social interaction with the more experienced individual guiding the learning process. Vygotsky (1978) promoted the idea of a 'Zone of Proximal Development [ZPD]' as one of the key principles of constructivism. He described ZPD as the distance of actual development that an individual is capable of and the potential that an individual has under guidance or with the help of peers. Vygotsky understood that learning is social in nature, which occurs through interaction with other people, i.e., interaction among students or peers' group and with the teacher (Singh &Yaduvanish, 2015). Hence, it can be inferred that guidance provided by the Chemistry teacher and peers during lesson instruction and the various types of in-class group activity might have influenced the students' conceptual understanding, which resulted in better academic achievement and writing assessment scores.

Additionally, these findings are congruent with the previous study conducted by Cetin (2014), who reported that explicit argumentation instruction using Toulmin's Argument Pattern has caused significantly better acquisition of reaction rate-related concepts and positively impacted the structure and complexity of pre-service teachers' argumentation. The result also aligns with a more recent study by Samosa (2021), who claimed that implementing the CER strategy significantly improved students' scientific argumentative writing skills in biology after the intervention, which is statistically significant with a $p < .001$. Samosa (2021) asserted that while extensive and complex, the CER strategy promises to build both argumentative writing skills and the students' science content knowledge.

The effectiveness of the CER strategy in this study was also supported by qualitative data based on document analysis. The document analysis performed using the rubrics adapted from Traut (2017) based on practical records, and test papers of experimental groups following the intervention have shown a well-structured scientific lab conclusion write-up with three components of CER. The sampled students' lab conclusion write-up showed an improvement in incorporating a compelling claim with appropriate and sufficient evidence in which reasoning uses relevant scientific principles and evidence linked to the claim compared to the pre-document analysis that implied a clear and scientifically sound claim supported by insufficient and irrelevant evidence with or without reasoning. This is because, under the guidance of a teacher, students who write in science use the constructivist approach (Vygotsky, 1978) to construct, organise, and think about laboratory processes they have experienced in the context of laboratory-based writing CERs. They then produce written text to explain the laboratory process and how the laboratory experiment connects to science concepts and process skills. As a result, science writing gives students a chance to fully articulate their understanding of the goals of the laboratory experiment. Students have a deeper understanding of the subject matter, for instance, when they actively apply scientific principles to explain occurrences in their laboratory investigation-based explanations (Zohar & Nemet, 2002).

Moreover, this qualitative finding corresponds to a similar study by Long (2014), who reported that students could structure their writing when asked to write an evidence-based explanation after exposure to the CER writing framework. This is because the CER strategy is viewed as a tool to support writing in science and help students nurture their conceptual understanding of science by allowing them to justify their scientific claims. Furthermore, Pichette (2018) reported that students improved in their use of evidence and reasoning to support claims in journal writing and lab discussions, and about half of the students showed growth in their argumentative writing assessment after the treatment period. Thus, a CER writing framework is literacy integration strategies that can help students better understand concepts, supports the development of explanations, and guides young children in communicating their understanding of science through writing (Zembal-Saul et al., 2013).

Therefore, the quantitative and qualitative findings of the current study confirmed that the CER strategy is effective for teaching Chemistry concepts and leveraging scientific writing skills, which is the most important part of scientific literacy. Furthermore, academic achievement and scientific argumentative writing skills were significantly improved when students were taught using the CER strategy than traditional teaching. This is because the explicit use of the CER strategy enhanced their understanding of the concept of Chemistry and retention of the information as the CER strategy provides students with active learning opportunities by creating a student-centered learning environment, allows students to express themselves, and increases students' academic achievement by providing more inclusion in the teaching process.

5.2. Students’ Perceptions of Explicit Use of CER strategy in Chemistry Instruction

The findings of SOSQ revealed that students possess a high level of perception toward the use of CER as an instructional method. If the teacher implements the CER strategy explicitly in their lessons, they can make the teaching period more effective, help students understand the rate of reaction better, and enhance their scientific writing skills. Some studies have reported that students preferred the CER strategy to the traditional lecture method (Atkinson, 2018; Cetin, 2014; Long, 2014; Samosa, 2021).

The finding from the interview responses further supplemented the results of the SOSQ. According to the student's responses to interview questions about their perceptions of the CER strategy, all the students found the lessons interesting and satisfying. Moreover, this kind of learning was found to be better than the traditional method as it requires students to participate actively in knowledge construction individually or in groups with various active learning activities. These views and stand made by students are congruent with the findings of Long (2014), who reported that overall positive attitudes about science increased from 52% to 63%, an 11% increase after the CER intervention in the grade 8 science students. Moreover, interviewees responded that CER activities were more fun and outgoing, made more sense to them, and allowed them to work together for knowledge construction.

The survey analysis of the theme 'conceptual understanding' has revealed a high perception level. Students have highly approved in the survey questionnaire that CER made learning easier and helped them to enhance their understanding of the Rate of Reaction concept. Students also agreed that CER enhanced the understanding of abstract concepts of Rate of Reaction. Congruently, students in the interview expressed that the students understood the concepts better when the lessons were taught using the CER strategy. In addition, students expressed that CER helped them easily understand the rate of reaction concept because they can connect the concept learnt in theory to a real-life situation. These findings were congruent with the study conducted by McNeil and Krajcik (2008), who stated that constructing explanations using CER helps students develop a deeper understanding of science content and improve their ability to write and critique scientific explanations. Moreover, Atkinson et al. (2020) found that the CER strategy enhanced students' understanding of Chemistry concepts while developing scientific explanations in an introductory level college Chemistry course. Further, Long (2014) stated that the strategy helped students to learn science content, improved their understanding of the nature of science, and helped them structure their writing when asked to write an evidence-based explanation after exposure to the CER writing framework. Thus, a CER writing framework is a literacy integration strategy that can help students better understand concepts, supports the development of explanations, and guides young children in communicating their understanding of science through writing (Zembal-Saul et al., 2013).

The survey analysis of 'Thinking skills' has revealed the highest positive perspectives of the students. Moreover, students in the interview expressed that CER is an innovative teaching-learning approach that improves their ability to think and communicate more scientifically by carefully analyzing evidence and backing up their claims. This result is consistent with the open-ended survey response conducted by Long (2014), who claimed that students had learned the CER method of answering questions, making them think about evidence to back up their claim and then give the scientific principle that supports their claim promoting thinking like a scientist. Moreover, Loch (2017) declared that the analysis and creation of claims based on evidence and reasoning are crucial life skills. Evaluating and making claims involves critical thinking skills and encourages students to be skeptical of claims made by others. This skepticism can lead to further research and the search for what evidence shows. Further, it has been shown that students who can think critically about concepts could make more content gains. This is because the ability to think critically allowed students to make more correct connections while they were processing and organizing new information. This whole learning process was intertwined, and students with better reasoning skills made more concept gains. Furthermore, it has been shown that scientific discourse in the classroom, guided by the Claim, Evidence, Reasoning, and Rebuttal [CERR] framework, increased high-level thinking about the content, and students made more profound connections within the material (Short et al., 2020). In addition, Traut (2017) also supported that using the framework allows them to organize their thoughts around the concepts and provides an opportunity to see what students are explicitly thinking in their reasoning, ultimately improving their science writing.

The results of the descriptive analysis of the survey questionnaire under the theme 'confidence' acquired a high average mean in the result section. However, the results of the interview revealed that students' opinions varied. For example, some felt that their confidence got boosted in using three components of CER in argumentative scientific writing, especially the lab conclusions. In contrast, others claimed that despite being aware of the three components of CER that construct a scientific explanation and argument, they could not incorporate all components because one must justify the claim with evidence, and one should be well-versed in scientific principles and theory. These views of students were congruent with the various research findings. For example, according to Traut (2017), students' confidence in the ability to support a claim with evidence shifted towards feeling more comfortable using evidence in their conclusion writing after the treatment period compared to the pre-treatment period. Similarly, the pre and post-survey analysis by Pichette (2018) with 54 biology undergraduate students has seen that most students' confidence in using evidence to support arguments improved after the intervention, though a paired t-test shows that the change is not statistically significant. Further, the gain of confidence in students was observed by Reamy (2020) in their ability to make evidence-based conclusions that supported a claim based on a given guiding question in the post-treatment period.

The survey analysis under the theme's ability to use components of CER' revealed highly positive perspectives on their ability to use three components in the scientific investigation or prompt-based CER activity in the result section. Most student interviewees expressed that they could include three components of CER in their lab conclusion report most of the time. Many researchers have validated these students' statements and found that students made gains between the pre-and post-writing assessment. The most significant gains were in stating clear claims and using appropriate and sufficient evidence. However, students still struggled with using reasoning appropriately in the post-assessment. This is because students might have easily associated a claim and evidence but not really have been able to connect the dots as to why they believed the evidence they chose fully supported their claim (Long, 2014; Traut, 2017). According to McNeill and Krajcik (2011), drawing conclusions using observations and prior knowledge and providing evidence to support those conclusions is a necessary skill for creating explanations in science classes. Hence, supporting explanations with evidence and learning to use evidence to conclude where skills students should have used in their everyday lives, not just for scientific purposes (Traut, 2017).

The finding of this study, based on a correlation analysis, further demonstrates that a significantly strong and positive correlation exists between the variables (e.g., interest, satisfaction, understanding, thinking skills, confidence, and components of CER as independent variables and the students test score and writing assessment scores as the dependent variables). Students' factors strongly correlate to their academic achievement and scientific writing assessment scores in the treatment group. The finding of the study is in support of Ruiz-Primo et al. (2008), who stated that the magnitudes of the correlations indicate that engaging students in the construction of high-quality explanations might be related to higher levels of student performance and interpreted that evidence that engaging students in the construction of explanations can lead to the expected positive impact on their understanding. Further, a comparison between CER artifacts and assessments scores found a general trend that the student did better on the assessment as the CER average increased, but no strong correlation existed (Traut, 2017).

Thus, the study's findings and inferences from the relevant literature conclude that students have a highly positive perception towards the CER strategy in enhancing the Chemistry concept and scientific writing skills, besides the difficulties faced in using different components of CER in constructing explanations and arguments as discussed in the next section.

5.3. Challenges faced by Students in Constructing Scientific Explanation and Arguments using CER Strategy

The finding from the open-ended survey questionnaires revealed that the majority of students expressed their difficulties in providing reasoning part both in verbal discourse and in writing scientific explanations or lab conclusions as evident from document analysis. The students' statements have been validated by many researchers who found that reasoning is the most challenging component to be incorporated in constructing scientific explanations and arguments (Atkinson et al., 2020; Becker, 2014; McNeill et al., 2006; McNeill & Martin, 2011; Traut, 2017), especially when attempting to incorporate scientific principles they do not fully understand into reasoning (McNeill et al., 2006). Atkinson et al. (2020) further stated that the challenges associated with that reasoning component might also indicate the pervasive struggle for students to understand the utility of scientific practices.

Students in the open-ended survey questionnaires have stated that using reasoning that connects data to claims is challenging as it requires a comprehensive understanding of the subject matter, including scientific principles and rules. These findings were congruent with the studies by Metz (2000) and Sadler (2004) that scientific content knowledge interacts with a student's ability to construct scientific explanations and arguments. This is because the student who has difficulty understanding the content knowledge will have difficulty constructing a scientific explanation and argument. After all, the construction of scientific explanations and argument requires knowledge of scientific explanations and arguments and relevant content knowledge (McNeill & Krajcik, 2008; McNeill et al., 2006).

Moreover, students have also experienced difficulties providing evidence while constructing scientific explanations and arguments because they are not sure which is considered good evidence and how much evidence to be listed to support their claim. This finding is in parallel to the study by Sandoval (2003), who stated that students often have difficulty selecting appropriate evidence to support or validate a claim, especially when presented with both appropriate and inappropriate evidence (McNeill & Krajcik, 2007). Often, adults and students will use opinion rather than evidence to support a claim (Kuhn, 1991); this may be because students find it challenging to determine what counts as scientific data that can be used as evidence from other types of information (Sadler, 2004). Further, a student's use of explicit evidence depends on what they see as the evidence required to support the scientific explanation and their ability to make sense of the evidence (Berland & Reiser, 2009; Sandoval, 2003). In addition to having trouble defining what constitutes appropriate evidence and explicitly stating evidence in scientific explanation and argument, students frequently struggle with defining what constitutes sufficient evidence, which is not surprising as scientists also often debate on what counts as sufficient data (Sandoval, 2003).

Students have also expressed that language is another factor that makes them struggle to develop structured scientific explanations and arguments using the CER strategy. This view of students was congruent with Fox (2020), who identified various language abilities that hinder accomplishing the skill of argumentation in science as another factor that makes the CER strategy challenging. Similarly, although CER is one strategy that has been shown to assist English Language Students; however, some studies reveal that ELL students do not always benefit from using CER. Kennedy and Folkes (2018) supported this view of students, who found that ELL students struggled with CER statements and became discouraged during the CER process due to language barriers.

To overcome challenges in reasoning and evidence selection, structured scaffolding approaches such as sentence stems and graphic organizers can support students in linking claims with relevant evidence (McNeill & Krajcik, 2011). Providing structured templates with guiding questions (e.g., "How does this evidence support your claim?") can help students articulate reasoning more effectively. Explicit instruction on evaluating evidence, along with model-based reasoning exercises, can further enhance students' ability to enhance conceptual understanding through inquiry (Sandoval, 2003). Peer discussions and collaborative argumentation activities also reinforce critical thinking in scientific explanations (Berland & Reiser, 2009). Similarly, language related barriers can be addressed through multimodal strategies, such as visual aids, technology, and creative activities can reduce the language load for learning science content and phenomena for students (Anish & Khan, 2023; Boyle et al., 2020). These active learning strategies can enhance students' ability to construct coherent and scientifically sound explanations using the CER framework.

6. Conclusion and Recommendation

The study investigated the impact of the CER strategy on academic performance and scientific writing skills in Chemistry, focusing on Grade IX students learning the Rate of Reaction. Using a convergent parallel mixed-method and quasi-experimental design, the research gathered data through achievement tests, scientific writing assessments, surveys, interviews, and document analysis. Findings revealed that students exposed to the CER strategy significantly outperformed those taught through traditional methods in both conceptual understanding and scientific writing, with female students demonstrating higher gains. The CER strategy was effective in improving students' confidence, critical thinking, and understanding of Chemistry concepts, although challenges were noted in reasoning and evidence construction due to language barriers.

Based on these findings, it is recommended that the Ministry of Education promote the CER strategy by integrating it into the Chemistry curriculum and facilitating teacher training. Specifically, professional development workshops focused on CER-based instruction should be developed to equip teachers with effective implementation strategies. Teacher training colleges should emphasize pedagogy related to scientific writing, and schools should enhance laboratory infrastructure to support experimental learning. Future studies should explore CER's application across grades and disciplines, involve teachers for broader insights, extend intervention durations, investigate gender-based performance disparities, and conduct qualitative analyses of improvements in each CER component to validate and expand upon these findings.

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