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Effect of Questioning Technique on Critical Thinking Skills in the Subject of Chemistry at Secondary Level

Muhammad Irfan[1]

Abstract

In contemporary science education, fostering students' critical thinking has become a pedagogical imperative, yet classroom practices often rely on lower-order questioning that limits cognitive growth. The present study investigates the effect of questioning technique on the development of inference and argumentation skills among secondary school students in the subject of Chemistry in Federal Government Educational Institutions (Cantt. & Garrison), Kharian Region, District Gujrat. Guided by Bloom's Taxonomy and constructivist learning theory, a quasi-experimental design was adopted involving 67 students of science of Grade 9 divided into control and experimental groups. The experimental group received instruction through structured higher-order questioning strategy for six weeks, while the control group experienced traditional teacher-led instruction. Pre- and post-tests measuring two critical thinking dimensions inference and argumentation were administered. Statistical analysis using independent t-test revealed significant improvement in the experimental group's overall critical thinking performance, particularly in inference, deduction and interpretation domains. These findings affirm that well-designed questioning frameworks can transform science teaching from rote learning to active inquiry. The study provides empirical support for integrating questioning-based pedagogies into Chemistry education and highlights the need for professional development programs that train teachers in promoting higher-order thinking across secondary science curricula.

Keywords: Questioning Technique (QT), Critical Thinking Skills (CTs), Inference, Argumentation

1 Corresponding author: Science Teacher Federal Government Institutions (Cantt. And Garrison), Rawalpindi, Pakistan
Email: Irfan673mmm@gmail.com

Introduction

In the contemporary educational landscape, the development of critical thinking skills (CTs) has become a defining attribute of quality education, particularly in the sciences. As societies transition toward knowledge-driven economies, learners' capacity to analyze, evaluate, infer and interpret information has become essential for success in academic, professional and civic life. Within science disciplines, chemistry holds a distinctive position due to its abstract concepts, complex theoretical structures and demand for analytical reasoning. Meaningful learning in chemistry extends beyond memorization; it requires conceptual understanding, reflective judgment and intellectual engagement (Tsaparlis, 2018).

Despite the recognized importance of these skills, instruction of chemistry at the secondary level in Pakistan is mainly guided by traditional, lecture-based learning methods. Within these educational environments, students are most commonly placed in a passive role of information recipient, rarely engaging in inquiry-based and reflective discourse (Memon, 2018). This approach to pedagogy limits the possibilities for higher-order cognitive engagement and often ends in a superficial understanding of the subject matter. As a result, the field of chemistry is generally viewed as a difficult and uninteresting subject, thus contributing to the decline in academic performance and excitement for scientific careers (Qadir & Fatima, 2021).

Critical thinking, as articulated by Gluck, Gilmore and Dilihunt (2015), entails rationality, precision and logical reasoning that enable individuals to derive valid conclusions from empirical evidence. These skills are foundational to chemistry learning, where experimentation, observation and evidence-based reasoning are central. Students lacking such competencies struggle to interpret data, draw conclusions or justify explanations scientifically. Hence, cultivating CT is vital for fostering problem-solving, innovation and scientific literacy in chemistry classrooms.

However, studies have repeatedly shown that development of critical thinking is not adequately addressed in the science education field, especially in developing countries (Holmes, Wieman & Bonn, 2015). In Pakistan, despite the National Curriculum for Science (2006) and Single National Curriculum (SNC, 2020) which focus on inquiry-based learning and higher-order cognitive outcomes, classroom practises very rarely indicate inquiry-based learning and higher-order cognitive outcomes.

Many educators still focus on content coverage rather than reasoning and exploration, which will reduce opportunities for students to hypothesize, analyze or pose critical questions (Sahamid, 2014).

Globally, the questioning technique (QT) has gained recognition as a powerful pedagogical tool for stimulating critical thinking. Rooted in the Socratic Method, it promotes reasoning through dialogue and reflection by encouraging learners to examine assumptions, justify responses and construct understanding collaboratively (Paul & Elder, 2003; Chin & Osborne, 2008). Ramsey et al. (1990) note that purposeful questioning transforms learners from passive listeners into active participants in meaning-making, fostering metacognition and conceptual clarity.

Within chemistry education, the process of asking questions is a link between empirical data and theoretical reasoning which aids the development of student exploration of causal relationships, validation of explanations and consideration of alternatives. The cognitive complexity of questions, according to King (1995) and Taba (1966), directly controls the profundity of analytical engagement of the learners. Nonetheless, in most of Pakistani classroom low order factual questioning dominates emphasizing on memorization and rote learning and neglecting the reasoning or synthesis (Khan & Inamullah, 2011). As a result, students rarely experience the cognitive requirements necessary for the development of higher order thinking skills.

An increasing body of scholarly scholarship has affirmed the role of questioning as a central pedagogical strategy for enhancing inference and argumentation - central elements of critical thinking (Paul, 2000; Zohar & Dori, 2019). Empirical studies that have been conducted by Alsaleh in 2020 and by Shanmugavelu et al in 2020 further suggest that questioning often dominates other active learning techniques in terms of promoting reflective and analytical cognition. Nevertheless, there is limited empirical data about the efficacy of questioning strategies in Pakistan chemistry classroom (Rehman, 2017; Nauman, 2017).

The concept of a "questioning technique" is defined as the strategic or random design of a strategy carried out by educators or facilitators to pose inquiries to learners for the purpose of provoking thought, assessing understanding, stimulating involvement, promoting higher order cognitive processes and guiding learning. The verb infer connotes the act of deriving an inference of a logical conclusion, usually something based on veracious or assumed factual evidence. The cognitive faculty of formulating and evaluating scientific arguments is increasingly being seen as a foundational element of critical thinking associated with science education. An argument is considered effective if the logical connection between the given reasons

and the resulting conclusion is evident and the conclusion is supported by the given reasons (Butterworth & Thwaites, 2013).

Statement of the Problem

Despite the emphasis in policy on quality education, the teaching of chemistry in secondary schools in Pakistan has been more or less teacher-centred where the focus lies on the memorization of information rather than on reasoning. This has hampered the critical and analytical skills of the students (Sumaira & Shahzada, 2017). While questioning-based pedagogies have shown potential to develop CT skills internationally, empirical evidence in Pakistan, particularly on chemistry education, is limited. Additionally, this is constituted research work since there is a major gap in studies regarding the effect of questioning technique on critical thinking skills of secondary students in chemistry within the local education system.

To fill this gap, the current study deals with the effect of questioning technique on critical thinking skill of secondary students in chemistry. Grounded in a quasi-experimental design, it tests the ability of structured, purposeful questioning to increase students' ability to infer argue logically. Conducted within the Federal Government Educational Institutions (Cantt and Garrison) in which traditional pedagogies are still dominant, the study aims to make evidence-based contributions to the enhancement of science instruction. The results of the study are anticipated to guide curriculum developers, policy makers and teachers who are interested in introducing inquiry-based teaching practices within the framework of science education reform in Pakistan.

Objectives of the study

Following were the objectives of the study:

1. To explore the proficiency of critical thinking skills among students in the subject of chemistry at the secondary level.
2. To investigate the effect of questioning technique on the different levels of critical thinking skills among the students in chemistry at secondary level.

Literature Review

Conceptualizing Critical Thinking

Thinking is a complex cognitive process that involves the

manipulation of mental representations of information (Holyoak & Morrison, 2012), includes several cognitive processes such as reasoning, problem-solving, decision-making and concept building (Sternberg & Sternberg, 2012). There are many categories of thinking which are found in the literature. Higher Order Thinking (HOT), for example, is associated to cognitive processes that go beyond basic memorization or recall of facts. It involves complex thinking tasks such as analyzing, synthesizing, evaluating and creating (Brookhart, 2010). But critical thinking is widely acknowledged as a higher-order cognitive process which involves various skills such as interpretation, analysis, inference, evaluation, explanation and self-regulation (Facione, 2015). Paul and Elder (2014) describe CT as disciplined thinking guided by clarity, accuracy, relevance, depth and fairness. Within science education, CT enables students to assess hypotheses, interpret data, draw logical conclusions and apply reasoning to new problems. However, Critical thinking (CT) is intrinsically linked to higher-order thinking, as both incorporate intricate cognitive abilities that transcend simple data memorization. Critical thinking (CT) is sometimes characterized as the ability to think clearly and rationally, understanding the logical connections between ideas, evaluating arguments, identifying errors or inconsistencies in reasoning, and solving problems systematically (Facione, 2015).

The development of CT skills is not only critical for academic success but is also seen as an important tool for students to become informed, engaged citizens who can critically evaluate information and make reasoned decisions (Facione, 2015). However, there exists many aspects of Critical Thinking and researchers rarely agree to the definition of Critical Thinking (Indah, 2020), such as making inferences, assumption and argumentation etc. as identified by the researchers.

The argumentation, discussion-debate and/or defending ideas are key practices that link Critical thinking with Science (Osborne, 2014). In chemistry, CT allows learners to evaluate experimental evidence, distinguish between theoretical and empirical claims and understand the probabilistic and inferential nature of scientific knowledge (Tsaparlis, 2018). Studies by Halpern (2010) and White et al. (2016) affirm that students with stronger CT abilities demonstrate greater conceptual understanding and scientific reasoning capacity. Therefore, fostering CT is both a cognitive and pedagogical imperative in science education.

The components of CTs opted for this study can be defined as; inference, the process of drawing conclusions from evidence and reasoning, often vital in scientific reasoning" (Facione, 2022). Critical thinkers must assess the assumptions behind any argument or hypothesis

in scientific inquiries" (Paul & Elder, 2014). Argumentation skills are essential for students to develop sound reasoning, particularly in scientific discussions and debates" (Erduran & Jiménez-Aleixandre, 2022). Cotton (2001) offers the most elucidating explanation of the term "question". He considers a question to be "any phrase with an interrogative function or structure." He further claims that in the classroom, instructor's questions are considered as instructional signals or stimuli that transmit' to students the subject" components to be taught as well as guidance for what' to do and how to accomplish it. Questioning technique refers to the strategies and methods employed by teachers to engage students in higher-order thinking by asking questions that stimulate critical thinking. In this study, it includes the use of probing, open-ended, convergent and divergent questions that challenge students to explore ideas, provide justifications, and critically evaluate concepts in Chemistry. In simple words, "Questioning technique is critical in fostering student learning and engagement by prompting students to think deeply and justify their reasoning".

Theoretical Foundations of Questioning in Learning

Teacher-initiated questioning during instruction promotes active learning and forces students to express, defend and apply what they know in different situations (Chin & Osborne, 2008). Consequently, the questioning technique is an efficacious pedagogical strategy. In this respect, its pedagogical relevance is incontrovertible. The technique is based on the old and distinguished Socratic Method, which favours the use of reasoning through dialogue. Socrates viewed questioning as a tool for provoking thought, discovering premises and helping learners gain deeper understanding (Paul, 2000).

The questioning technique is importantly tied to the theory of constructivism. Constructivists believe that learning is an active process in which people reorganize their previous knowledge and experience (Piaget, 1973; Vygotsky, 1978). This viewpoint argues that learning is mediated by a social interaction, linguistic communication and guided inquiry. Bruner (1996) went on further to argue that structured questioning would help the learners to guide themselves through the process of discovery. As a result, interrogative methods that focus on probing thinking may generate metacognitive awareness and facilitate the meaning building process on the side of the learners. These methods facilitate active participation of students, lead to the development of critical thinking skills

and independent knowledge seeking behavior according to Cotton (2001). To conclude, questioning is one of the basic methods of active learning.

Using questioning techniques as a teaching tool

Questioning is multifunctional in the classroom: it helps to stimulate curiosity and reflection, and is also rich in facilitating dialogues between teacher and students. Chin and Osborne (2008) show that higher-order questioning can increase inquiry behaviours as well as cause conceptual change in science classrooms. In a similar vein, King (1995) demonstrates that explicit questioning techniques have a major positive impact on student reasoning and problem-solving.

Research has differentiated between low-order questions, which evaluate factual recall, and high-order questions which elicit analysis, evaluation and synthesis (Taba, 1966; Zohar & Dori, 2019). Empirical findings have shown that high-level questions increase students' cognitive engagement and therefore promote abstract thinking and logical reasoning (Alsaleh, 2020). However, research in developing countries like Pakistan shows that most of the questions asked in the classroom are either fact or procedural based and very little higher order thinking is elicited (Khan & Inamullah, 2011).

Relationship between Questioning and Critical Thinking

A growing body of evidence supports the claim that structured questioning is directly linked to the development of CT. Paul and Elder (2002) argue that CT itself is question-driven. Effective questions compel learners to justify, interpret and challenge assumptions. Similarly, King (1995) demonstrated that deliberate questioning strategies significantly improve students' reasoning and problem-solving abilities. Studies by Chin (2007) and Shanmugavelu et al. (2020) demonstrate that inquiry-based questioning strategies improve students' analytical and inferential reasoning, particularly in science subjects.

Questioning fosters the dimensions of CT **inference** and **argumentation** by encouraging learners to examine evidence critically, draw conclusions and articulate reasoning processes. When teachers employ open-ended and reflective questioning, students learn to construct explanations, evaluate multiple perspectives and develop intellectual autonomy.

Ways to Ask Questions in Chemistry Class

Chemistry is complex by nature and appropriate teaching methods

for developing students' conceptual understanding are needed. Empirical evidence suggests that inquiry-based methods increase understanding of molecular structure, chemical equations and reaction mechanisms by integrating conceptual and procedural knowledge (Atkin, 2013). King (1995) stated that questioning by teacher is calibrated with the higher-order cognitive levels of Bloom's taxonomy, which enhances the students' scientific reasoning skills and experimental skills.

Current research (specifically Zohar and Dori, 2019) has demonstrated, however, that the use of questioning can improve the levels of engagement with the chemical material, and hence the integration and combination of theoretical knowledge and practical laboratory experience. By contrast, contextual research in Pakistan (Nauman, 2017; Rehman, 2017) reveals a lack of use of these approaches; teachers often prioritize curriculum coverage over inquiry, thereby limiting chances of cognitive growth. This difference highlights the need to carefully investigate the role of questioning in critical thinking in Pakistani chemistry classrooms.

Critical Thinking in the Context of Pakistan

Educational reforms in Pakistan as embodied in the National Curriculum (2006) and Single National Curriculum (2020) make thinking critically and learning through inquiry indispensable 21st century competencies. However, barriers to implementation persist, especially in science disciplines, where the preparation of teachers and how they teach often continue in traditional ways (Hasil, 2012).

Subsequent investigations (Qadir & Fatima, 2021; Hoodbhoy, 2009) attribute the deficient cultivation of critical thinking to the teacher centred pedagogies and examination driven assessment mechanisms. Students are rarely encouraged to ask questions, reason through problems or examine alternative explanations. This contextual reality makes pedagogical innovation, including the questioning technique necessary in order to resolve curriculum intentions with the realities of the classroom.

Previous Studies

A considerable amount of literature shows that there is a strong relationship between teachers' questioning techniques (QT) and various aspects of student learning such as academic achievement, retention, in-class participation and the development of critical thinking skills (CTs). Scholars have concurred to a great degree that cognitive development and reflective thinking are triggered through questioning and not through

definitive answers. Hassan et.al.,(2020) found that questioning in the classroom significantly improved the critical thinking of students especially in written expression. Similarly, Wilen (1991) stressed that students' engagement and depth of learning are directly influenced by the complexity and cognitive demand of questions by teachers, an idea that also holds when viewing the research done by Cotton (2001) who discussed the use of questioning as an instructional stimulus that activates the learners' responses towards the lesson content. Empirical findings further suggest that the questioning practices of teachers show positive correlation with the academic achievement, participation and retention of students (Nasreen, 2003).

Mayberry and Hartle (2003) noted that the effective questioning techniques encourage active student involvement and maintain intellectual curiosity. Their study made a basic distinction between instructional and conversational questioning, suggesting that the former is aimed at encouraging critical reasoning, unravelling misunderstandings and evoking analytical language. In line with this argument, Khan and Inamullah (2011) recognized questioning as one of the essential aspects of effective pedagogy arguing that teachers should model the ability to pose cognitively challenging questions in order to develop students' critical thinking skills. Elder and Paul (2003) also found that effective questioning promotes motivation, stimulates deeper information processing and guides learners toward mastery of content by means of self-inquiry and active participation. Elder and Paul (2010) later replicated these results and showed a positive relationship between higher-level questioning and student achievement in analytical and application-based tests. This result was further supported by Chikiwa and Schafer (2018), whose study confirmed that teachers' use of higher order questions makes a significant contribution to the development of students' capacity in critical thinking skills. Chin and Osborne (2008) also proved that QT improves learners' analytical and synthetic skills and thus their concept understanding.

A number of studies have been done on the Socratic and probing types of questioning. Paul and Elder (2006) presented a taxonomy of follow-up questions which encourage reflection, question assumptions and test reasoning which makes a good adaptation for the chemistry classroom. Zhao (2013) stressed the significance of creating authentic dialogue and thinking time with the development of critical thinking, and Santoso, Yuanita, and Erman (2018) stated that students need scaffolding guidance to build self-directed questioning and analytical skills. Moreover, Chin and Osborne's (2010) complementary research which also showed that explicit teaching of questioning and argumentation results in more

conceptual change, supports the interdependence of inquiry and logical thought.

Numerous empirical studies affirm the relationship between QT and CT in diverse contexts. First, Cotton (1988) and later on Hassan Malik (2017) advocated the deliberate use of higher-order questions to elevate learners' cognitive engagement.

Miri, David and Uri (2007) found that the three-year implementation of higher-order questioning of science students significantly increased the students' analysis and evaluation skills. Similarly, Abrami et al. (2015) used a meta-analysis of 341 studies and found a statistically significant mean effect size (0.58) that supported the effectiveness of questioning strategies in promoting critical thinking. Regarding the education of chemistry, Santosa, Yuanita, and Erman (2018) discovered that question-based instruction leads to predictive, inferential, and evaluative aspects of critical thinking.

The universal pedagogical importance of questioning is supported by additional evidence offered in English as a foreign language contexts (Feng 2013; Al-Darwish 2012; Chin 2007). Higher-order questioning, especially one with the use of Socratic Method, has been shown to nurture analytical, inferential, and evaluative reasoning. Almeida (2010) found that teachers' questioning patterns influenced students' creative and critical engagement across disciplines, including chemistry. Chew, Lin, and Chen (2019) later confirmed the positive effect of Socratic questioning on students' critical reasoning performance.

Research also emphasizes the role of QT in strengthening particular CT constructs; inference, and argumentation. Mason (2007) noted improved levels of inferential reasoning in chemistry students that were encouraged to ask and answer questions.

Collectively, these studies lead to the conclusion that questioning plays a central role in the development of CT in science education. Learners who are exposed to structured, higher-order questioning show better reasoning, problem-solving and conceptual understanding. Despite the plentitude of evidence, the concept of the impact of QT on CT in particular has still been indicated with a lack of empirical research work that focuses on the impact of QT on CT in the context of secondary chemistry education in Pakistan, Memon, 2018. Thus, more research is needed to investigate the pedagogical effectiveness of QT in promoting critical thinking in chemistry learners at this level.

Research questions and hypothesis of the study

The research questions are as under:

1. What is the current proficiency of critical thinking among science students at the secondary level?

Null Hypothesis

***H_1*:** There is no significant effect of questioning on developing the students' skills to infer the information in the subject of chemistry at secondary level.

***H_2*:** There is no significant effect of questioning on developing students' skills to argument in the subject of chemistry at secondary level.

Delimitation of the Study

Due to time and resource constraints, the study was confined to FG Public School (Boys), Kharian Cantt, District Gujrat, focusing exclusively on Grade 9 science students studying chemistry. The findings, therefore, apply primarily to similar institutional and demographic contexts within FGEIs (C/G) schools.

Research Methodology

The research design adopted for the current research was a quasi-experimental, non-equivalent control group pretest–posttest design to investigate the effect of the questioning technique on the development of critical thinking (CT) skills among secondary school students in Chemistry. This design was appropriate due to lacking of random assignment of the participant allowing intact groups allowing the comparison of two intact groups one receiving instruction through questioning technique (experimental group) and the other receiving conventional instruction (control group) to determine students' CT skill development.

Population and Sampling

The target population comprised all Grade IX students studying Chemistry in Federal Government Educational Institutions (Cantt/Garrison) of the Kharian Region, Punjab, Pakistan. According to the data provided by the Regional Office, approximately 403 students were

enrolled at the secondary level across six federal public schools in the region.

The accessible population was limited to students of FG Public School (Boys), Kharian Cantt, due to ease of access, administrative approval and availability of two intact science sections. Two existing sections of Grade IX, each following the Federal Board of Intermediate and Secondary Education (FBISE) curriculum were selected purposively as intact groups.

- Experimental Group (IX-A): 33 students
- Control Group (IX-B): 34 students
- Total Sample: 67 students

Both groups were comparable in age, academic background, and prior achievement levels, ensuring baseline equivalence prior to treatment implementation.

Research Instrument

Development of Critical Thinking Test (CTT)

A standardized Critical Thinking Test (CTT) was designed to assess students' critical thinking skills i.e. inference and argumentation skills of Grade 9 in the subject of Chemistry. The test was modified from two globally recognized assessments: the Cornell Critical Thinking Test (CCTT) and the Watson–Glaser Critical Thinking Appraisal (WGCTA). Items were linked with the two CT constructs i.e. inference and argumentation as described by Ennis (1985) and Halpern (2010). Item analysis was carried out and poor or invalid items were either revised or eliminated after piloting. The final test had 25 multiple-choice questions (MCQs). Each question was worth one point. Items were created for each CT component, making sure that all domains, inference and argumentation in this case, were equally represented and measured in a balanced way. Each question had three choices: "Yes," "No," and "Maybe." This made pupils think about their answers instead of just remembering what they had learned.

Adaptation of Culture and Curriculum

To make sure they were relevant to the setting, the items were changed to fit the Chemistry curriculum set by FBISE in Islamabad. The language and examples were changed to fit the Pakistani secondary school system. Test items aligned with particular Student Learning Outcomes

(SLOs), including balancing equations, predicting reaction outcomes, analyzing data, and identifying chemical linkages.

Intervention Procedure

The intervention lasted for a six week period starting in September 2022 and ending in December 2022. Both the experimental and control groups interacted with the same Chemistry content following the Federal Board of Intermediate and Secondary Education (FBISE) curriculum, i.e. Units 1, 2, 3 and 8. These units included such topics as oxidation-reduction reactions, periodic properties, physical properties of gases, liquids and solids, mole concept, electronic configuration, and chemical calculations.

Experimental Group

The researcher taught the experimental group using the Questioning Technique (QT) which is based on the Socratic and Constructivist approaches. To ensure transparency and equity lesson plans were developed to include higher-order questions that helped students improve their skills in making inferences and arguing. The teacher not only posed the questions to the students but also students were urged to ask and answer open-ended questions during lessons, which created a dialogic learning atmosphere.

Control group

The students of control group received instruction by conventional methods such as lecture method, book reading etc. by the subject teacher. Apparently, this strategy focused more on delivering information and memorizing it than on asking questions or using logic necessary for cognitive engagement.

Results

Baseline Proficiency in Critical Thinking Skills

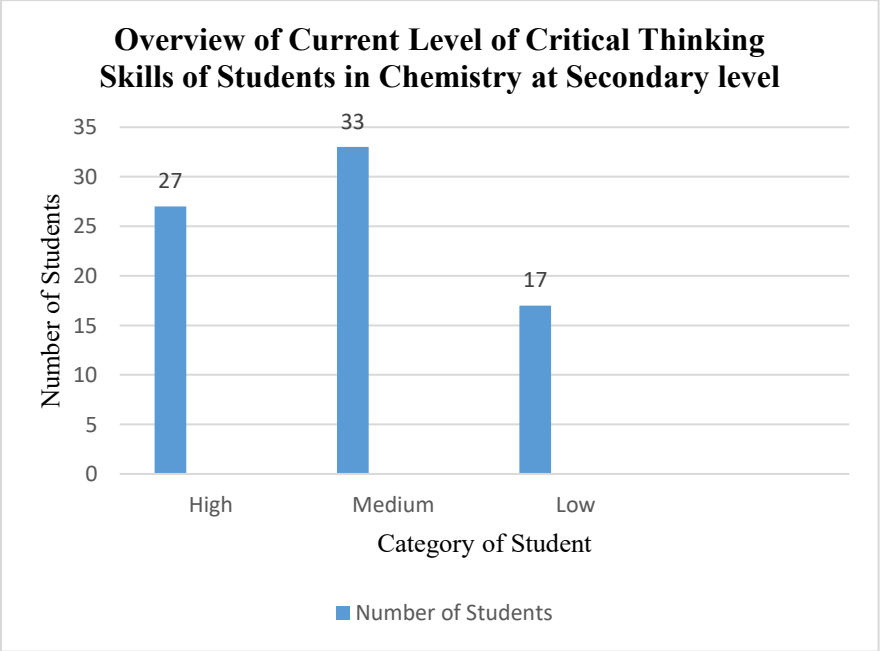
The first objective of this study was to assess the existing proficiency levels of students' critical thinking skills (CTs) of Grade 9 in Chemistry. This objective was achieved by administered to all 67 participants before implementing the questioning technique to the students. This pretest was

based on the *Watson–Glaser Critical Thinking Appraisal (WGCTA)* and *Cornell Critical Thinking Test (CCTT).*

The pretest results showed that the highest marks obtained by the students were 22 and the lowest scores were 7, which gave a range of 15 points. Accordingly, the overall critical thinking proficiency of the students was categorized in three levels: Low (7-11), Medium (12-17) and High (18-22). The data showed that most students about 49% had the medium level of critical thinking, 40% had the low-level proficiency and only 11% had the advanced critical thinking. This baseline distribution indicated that the majority of students were relying primarily on rote memorization with little evidence of analytical or inferential reasoning.

Figure 1

Pre-Intervention Comparison of Critical Thinking Components



To determine the initial equivalence of the control and experimental groups before the intervention, independent samples *t*-tests were conducted for each critical thinking component.

Table 1

Results of Pretest indicating Proficiency level of Inference skills of control group and experimental group before intervention

Group	Test	n	Mean	SD	df	t-value	Sig (2-tailed)
Control	Pretest	34	2.64	0.73	65	1.41	0.16
Experimental	Pretest	33	2.36	0.89			

The outcomes of the t-test showed that the mean difference between the two groups (2.64 vs. 2.36) was not statistically significant (*sig* (2-tailed) = 0.16). Both groups exhibited comparable baseline levels of inference skills. It confirmed the homogeneity of both the groups prior to treatment.

Figure 2

Proficiency Level of Inference Skill of Control and Experimental Intervention

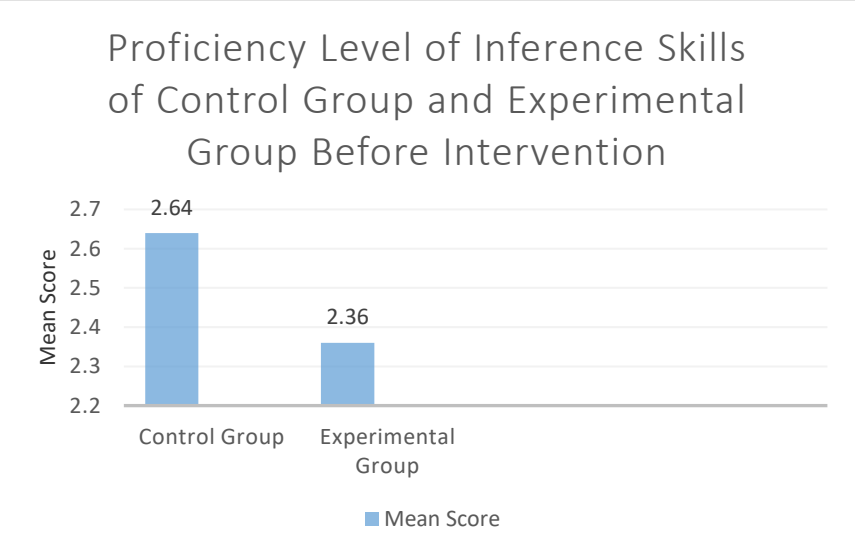


Table 2
Argumentation Skills

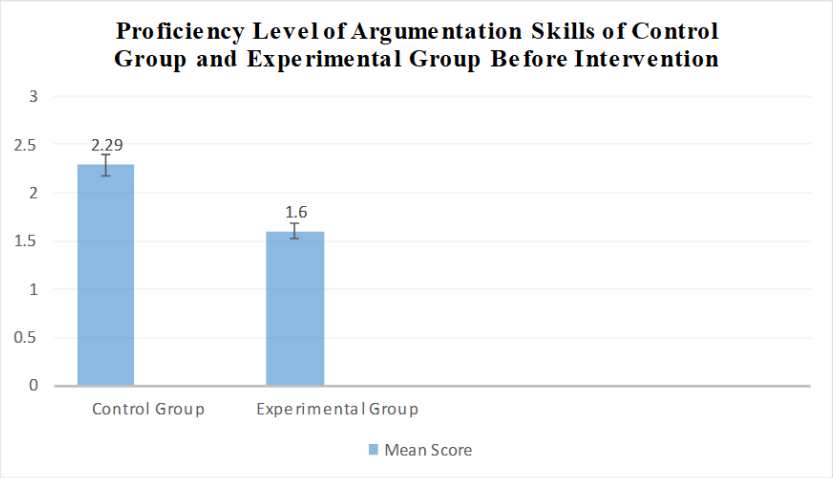
Results of Pretest indicating proficiency level of Argumentation skills of control group and experimental group before intervention

Group	Test	n	Mean	SD	df	t-value	Sig (2-tailed)
Control	Pretest	34	2.29	1.26	65	2.58	0.12
Experimental	Pretest	33	1.60	0.86			

The control group had a slightly higher mean score than that of experimental group. However, the difference existed between them was statistically insignificant, *Sig (2-tailed* value is 0.12. Thus, both groups were deemed equivalent in argumentation skills at the start of the study.

Figure 3

Proficiency Level of Augmentation Skills of Control Group and Experimental Group Before Intervention



Post-Intervention Analysis

Following the six-week instructional intervention, posttest data were collected and analyzed using independent samples *t*-tests to evaluate the effect of the questioning technique on students' critical thinking performance.

Table 3
Inference Skills
Posttest Comparison of Inference skills between control group and experimental group

Group	Test	n	Mean	SD	df	t-value	p-value	Sig (2-tailed)
Control	Posttest	34	2.79	0.84	65	-2.40	0.43	0.01
Experimental	Posttest	33	3.33	0.98				

The mean score of the experimental group (3.33) was higher as compared to compared to the mean score of control group (2.79). The sig (2-tailed) value is 0.01, indicated that both the groups were statistically significant different. This indicated that questioning-based instruction enhanced inference making skills of the students of the experimental group. Thus, questioning technique enabled them to draw evidence-based conclusions more effectively.

Figure 4

Proficiency Level of Augmentation Skills of Control Group and Experimental Group After Intervention

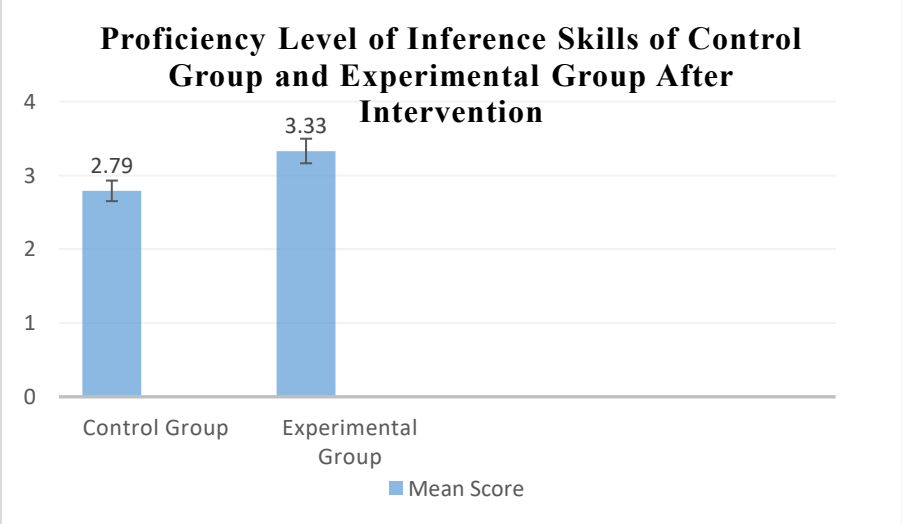


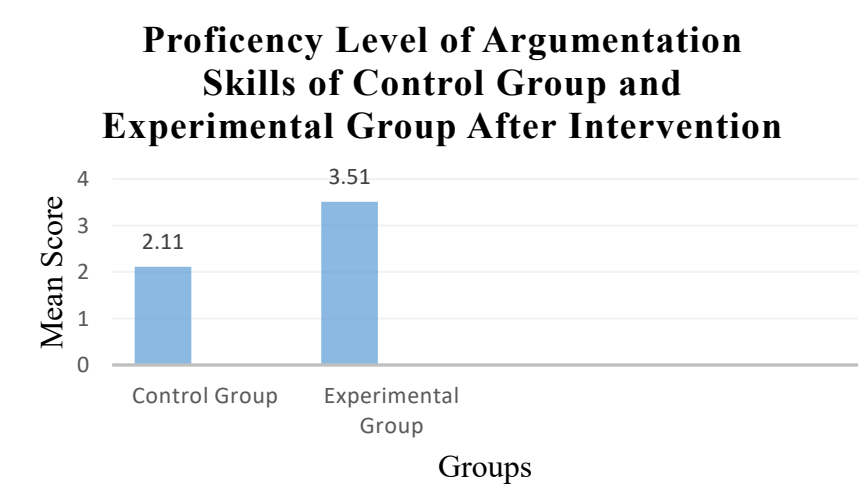
Table 4
Argumentation Skills
Posttest Comparison of Argumentation skills between control group and experimental group

Group	Test	n	Mean	SD	df	t-value	p-value	Sig (2-tailed)
Control	Posttest	34	2.11	1.12	65	-5.68	0.19	0.000
Experimental	Posttest	33	3.51	0.87				

The posttest results asserted a significant improvement in argumentation skills, sig (2-tailed) value is less than 0.001showing that among students of the experimental group who received instructions the questioning technique. On the other hand, the argumentation skills of the students of the control group were increased to some extent but the experimental group showed a **notable increase in their ability to construct, evaluate and defend scientific arguments,** affirming the rejection of Null Hypothesis H_2.

Figure 4

Proficiency Level of Augmentation Skills of Control Group and Experimental Group After Intervention



The results of this study have been presented in the previous section. The findings of this study are consistent with the existing research in a way that questioning techniques (QT) significantly enhance students' critical thinking skills (CTs). This is quite relevant, particularly within secondary-level education in the disciples of science subjects such as physics, chemistry biology etc. The comparative analysis of pretest and posttest results between the control and experimental groups revealed marked improvement in the experimental group's CT components in respect of inference and argumentation. This improvement validates earlier scholarly claims that active learning strategies, when embedded in instruction, play a central role in advancing students' cognitive development.

Although the use of questioning as a teaching strategy in chemistry is widespread in many countries, its utilization in Pakistan is not common. The present study offers empirical evidence that structured questioning can significantly enhance students' understanding of challenging chemical concepts and their capacity for critical analysis of information. As noted by Bonk (1990), while many instructional strategies may impact on learning, it is the teacher questioning that is carefully used that prompts student thinking the most. It was by means of pretest results on the control group that it was suggested that some elements of CT may be inherent among learners, but then were further reinforced after the exposure to a systematic questioning procedure in the experimental group. Therefore, the posttest results substantiate the contribution of QT in the development of critical and reflective thinking among the secondary level chemistry students.

The findings from the inference skills confirm the conclusions of Paul and Elder (2006) and Chin and Osborne (2008) that higher-order questions improve students' analytical skills because they require students to make logical connections among concepts. Also, there was an increase in the students' ability to interpret the results as evidence that questioning facilitates deeper learning of chemical equations and data representation in the students who were in the experimental groups.

There was also a significant improvement in argumentation skills. Students in the experimental group showed greater capacity to formulate, justify and evaluate scientific arguments than did their peers of the control group. The findings are in accordance with the results of Kristianti, Ramli and Ariyanto (2018) t questioning techniques can increase argumentation and reasoning from evidence. The findings also support those of Chin and Osborne (2010) that the sustained questioning leads to conceptual understanding and critical discourse skills. Paul and Elder (2006) and

Vygotsky (1978) also suggested that reflective argumentation occurs through dialogic questioning through collaborative inquiry and social interaction.

Overall, the results of the study are aligned with the results of Miri et al. (2007) and Zoller and Pushkin (2007) who stress the importance of higher order questioning in the enhancement of CT in science teaching. The results indicate that questioning encourages scientific question-based essential skills; observation, reasoning, the development of hypotheses and experimentation, thus stimulating autonomous intellectual development.

Conclusions

This study concludes that questioning techniques are a powerful pedagogical tool for enhancing students' critical thinking in Chemistry at the secondary level. Compared with conventional instruction, questioning-based strategies fostered deeper engagement, inquiry and reflection, core tenets of constructivist learning.

By consistently integrating higher-order and open-ended questions into classroom discourse, teachers encouraged students to move beyond factual recall toward making inferences and argumentation dimensions central to higher cognitive domains.

The findings align with previous international studies (Paul & Elder, 2006; Zoller, 2012), which affirm the efficacy of questioning in cultivating analytical and metacognitive thinking. Within Pakistan's educational context often dominated by teacher-centered instruction this study provides empirical evidence that interactive questioning can bridge the gap between content mastery and conceptual understanding.

In essence, the study substantiates that systematic use of questioning techniques significantly enhances inference and argumentation skills, thereby cultivating the critical thinking competencies essential for success in 21st-century scientific learning.

Such evidence reinforces the argument that reforming science education through inquiry-oriented pedagogies can produce globally competitive learners capable of scientific reasoning, innovation, and problem-solving.

Recommendations

Based on the study's findings and conclusions, following recommendations for consideration are hereby presented below in accordance with recommendations derived from the findings:

1. It is advisable for the educators to implement questioning technique to cultivate inference skills, a vital component of CT, among the secondary school students in the subject of chemistry.
2. It is advisable for the educators to implement questioning technique to cultivate argumentation skills, a facet of CT, among the secondary school students in the subject of chemistry.

Recommendations for Future Research

The outcomes of the current study provides multiple opportunities for the researcher to evidence the efficacy of questioning technique in various disciplines of science.

1. The current research was conducted in the field of chemistry, however, the effectiveness of questioning technique may be explored in other disciplines of science including physics, chemistry, biology etc. at secondary level.
2. Mixed Method Research can be conducted to investigate the holistic perspective and lasting impacts of QT over time within the domain of chemistry or other scientific disciplines.
3. In future, efficacy of peer questioning may be explored.

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