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Critical Thinking Skills Development among Secondary School Students: An Analysis of Chemistry Textbook Grade X (2020)

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The current study used qualitative analysis of the Chemistry textbook grade X through the facilitation of NVivo 12 software to analyze the textbook about critical thinking skills development. The textbook was selected through purposive sampling. The findings revealed that the textbook fostered critical thinking skills through several approaches relevant to chemistry concepts in to real-world, and their applications, asking open-ended questions, presenting merits and demerits of chemical processes, offering flow diagrams of industrial systems, comparing related concepts, and illustrating underlying chemical principles behind the phenomenon. The book urged students to apply chemistry principles critically in practical settings, evaluate them from different perspectives, rationalize complex processes thoroughly, and analyse their strengths and weaknesses in various approaches. Additionally, it invited them to discover the logic behind complex chemical systems and question what drives chemical behaviors at core levels. Moreover, explicit instruction on developing critical thinking skills should be better integrated into the curriculum with inquiry-based activities.

1. Introduction and Literature Review

Critical thinking is decisive for academic success both now and in the future. This skill involves analyzing information logically to make informed decisions (Changwong et al., 2018). In science education especially, it is a key to understanding complex scientific ideas to use them effectively (Dwyer et al., 2014; Connor et al., 2023). Critical thinkers can break down problems into smaller pieces; synthesize lots of data into one point; think about what was learned; ask clear questions based on evidence; see gaps in reasoning; use logical reasoning; support claims with evidence from many different sources; understand how things change over time; connect big ideas across multiple fields by identifying common themes or principles that link many concepts together.

Textbooks are important tools for both teachers and learners (Upahi & Ramnarain, 2019). They provide the framework of the curriculum and present key concepts and exercises (Khine, 2013; Gumilar & Ismail, 2023). Textbooks are known to have a great influence on students' critical thinking skills either positively or negatively (Taleb & Chadwick, 2016; Kafri, 2022). Researchers have found that the way textbooks are written and presented has a significant effect on how learners acquire these critical skills.

All sciences rely on critical thinking. But it plays a special role in chemistry (Yoon et al., 2014; Yang et al., 2021). Analysis and synthesis are two forms of thinking that refer to the breaking down and piecing together of things, respectively (Danczak et al., 2017; Bowen, 2022). When chemists interpret their observations or attempt to solve problems, they must think in these ways. It is also worth mentioning that people who can think critically will be more likely to understand why chemical reactions happen the way they do. And when they have that knowledge, they will be able to make predictions about how other reactions might go (Schunk & Zimmerman, 2011; Torrington et al., 2024). They may also be better equipped to interpret their observations accurately. In short, good critical thinkers will often excel in higher levels of science education.

Critical thinking is an important skill to have in science, but it's especially vital for chemistry. Researchers Yoon et al. (2014) and Busenbark et al., (2022) mention that this type of thinking is needed while interpreting, observing, and problem-solving. The textbook itself also includes open-ended questions that demand deep analysis and synthesis — which individuals thinking critically might take a step further with understanding the principles of chemical reactions. Moreover, they can make predictions based on these principles for further interpretation and observations. That is why critical thinking skills development in Chemistry is necessary for the student's success in higher-level learning and the development of higher order thinking.

There are numerous studies conducted concerning the development of critical thinking skills in education. Vieira et al. (2011) and Vieira et al. (2023) explored whether explicit instruction and infusion approaches can improve elementary school science students' critical thinking skills. It was revealed that both methods were more effective than traditional teaching styles in improving their skills. In the same way, Abrami et al. (2015) and Mao et al. (2022) conducted a meta-analysis of multiple instructional interventions devised for critical thinking development. It was concluded that explicit instruction, mentoring, and collaborative learning all had significant positive effects on students' critical thinking skills improvement.

Many studies have been done when it comes to promoting critical thinking skills in chemistry classrooms as well. For example, Gupta et al. (2015) tested inquiry-based learning's effectiveness with high schoolers Saputro et al. (2018) looked at undergraduate courses taught with problem-based lessons. Both studies saw significant improvement in their student's analytic capabilities after implementing those strategies. Upahi & Ramnarain (2019) analyzed chemical phenomena representations in a secondary school textbook. The authors concluded that the simplified representations within textbooks may be limiting students from thinking more critically about the subject. They recommended future books include authentic and complex illustrations instead to foster better critical thinking skills.

In the Pakistani context, very little research has been done to see how much textbooks contribute to critical thinking. However, there have been a few studies that suggest a reform in textbooks is needed to include critical thinking elements. In a study conducted by Zamir et al. (2021), in a university context regarding the effective pedagogies for the development of critical thinking skills. Lecture methods, discussion, storytelling, argumentation, and presentations with writing assignments are discussed to be effective for CT skills development. Moreover, there are several studies have been conducted looking into this topic across many different areas of study. In one study Ali et al., (2017) concluded that general science textbooks for grades VI-VIII lacked higher-order thinking questions and activities. The remedy to this the study said, was to include more critical thinking-oriented content in the books to enhance students' cognitive skills. Another study conducted by Shahzadi & Khan (2020) to explore the CT skills correlation with students' academic achievement among intermediate students. The findings revealed low dimensions of critical thinking e.g. logic, analysis, and evaluation. Also, there was found significant positive correlation between CT skills and students' academic achievement. In the same way, different studies have been conducted in this perspective as an analysis of education policy and science teachers' practices for CT skills development (Jamil, 2021); analysis of the Physics, chemistry, biology, and mathematics curriculum for the development of CT skills among students (Jamil et al. 2024; 2024a; 2024b); an analysis of Physics textbook for grade IX regarding CT skills development (Jamil et al., 2024); single national curriculum social studies for critical thinking skills development (Jamil, et al., 2024); teachers' perspective and qualitative content analysis of policy and curriculum documents for this phenomenon (Jamil & Muhammad, 2019; Jamil et al., 2020; Jamil et al., 2021); and critical thinking skills development of Pakistan studies, analysis of the document (Naseer et al., 2022).

The current study aims to analyze the textbook of chemistry, and how it plays a role in fostering critical thinking skills among science students at the secondary level. Through analyzing the content and structure of the textbook, it can be determined what essential skills are discussed in the textbook. The study results will guide textbook developers, designers, and authors while writing and creating these resources and encourage the students to think critically in the chemistry subject. Resultantly, it will increase the quality of chemistry teaching-learning. Furthermore, this research can be used to reinforce discussions on science education and educational policies to encourage critical thinking skills among secondary school students.

1.1 Research Questions

1. How does the grade X chemistry textbook facilitate the development of critical thinking skills among students?
2. What strategies and elements within the textbook contribute to the cultivation of critical thinking abilities in chemistry?
3. To what extent does the textbook provide opportunities for students to engage in critical analysis, evaluation, and problem-solving?

2. Research Methodology

The current study employed a qualitative content analysis approach to analyze the Chemistry textbook regarding the development of CT skills among secondary school science students. The current method is the most suitable one since it systematically interprets the large textual data to identify its themes, patterns, and meanings (Kyngäs, 2020). For textbook analysis, this approach is considered the most suitable in educational material like textbooks to get insights from the content and its learning outcomes (Mayring, 2014). The Chemistry textbook (downloaded from *https://pctb.punjab.gov.pk/E-Books*) for grade X (2020) was selected through a purposive sampling technique. This technique was used based on specific criteria and characteristics (Etkina et al., 2006). NVivo software was used as a facilitator for qualitative content analysis (Jackson et al., 2019). Moreover, NVivo is used for data organizing, analysis, and textual data efficiently (Silver & Woolf, 2018).

3. Findings of the Study

The following are key findings after the analysis of the Chemistry textbook for grade X.

3.1 Connecting Concepts to Real-World Applications

By frequently linking chemistry concepts to real-world industrial processes and applications, the textbook encourages students to think critically about how chemistry is relevant in everyday life. This moves beyond just memorizing facts to analyzing how chemical principles explain real phenomena. For example, on page 19 it describes how *"Wood fire can be extinguished by throwing water on it"* while *"Oil fires can't be put out with water because oil and water do not mix"*. Students must analyze the intermolecular forces and polarity of each substance and critically reason why water is effective for wood fires but not oil fires. Consistently making these real-world connections helps students build the critical thinking skill of applying chemistry concepts to actual scenarios and critically explaining observations in terms of chemical principles. Students will be able to take a situation, identify chemical concepts relevant to the problem at hand, link concepts together then reason through how each concept applies within the real-world scenario provided.

3.2 Open-Ended Questions Requiring Analysis

The open-ended questions at the end of each section go beyond factual recall and prompt students to think critically to construct thorough, well-reasoned responses. These questions often require students to analyze and synthesize multiple pieces of information and critically explain chemical processes in depth. For instance, on page 23 one of the questions is *"Write a note in detail on smelting and bessemerization, giving a specific example."* this requires pulling together the descriptions of smelting and bessemerization from the text and critically explaining the key steps and chemical reactions involved in each process. Students must analyze how these processes are used to extract and purify metals and apply their understanding to provide a specific example. Having to critically deconstruct and explain these complex processes in writing deepens conceptual understanding and builds the skills to analyze intricate chemical systems. Regular practice with these kinds of open-ended synthesis questions gives students experience with the critical thinking needed to break down problems, identify key pieces of information, and construct clear scientific explanations and arguments.

3.3 Describing Advantages and Disadvantages

In sections like the description of the Solvay process, on page 11 it states advantages of the Solvay process like *"It is a cheap process as raw materials are available at very low prices"* and *"Process is pollution free, because the only waste is calcium chloride solution."* Considering advantages and disadvantages builds critical thinking skills. This encourages students to think critically and evaluate the pros and cons from multiple angles. For the Solvay process, students must consider the economics of the low-cost, available raw materials, the environmental impact of the minimally polluting waste products, the energy efficiency of not having to evaporate solutions, and the ability to recycle reactants like ammonia and carbon dioxide. Thinking through these different factors requires critically analyzing the chemistry as well as the broader context and implications. They will also be given practice with reviewing both the positive and negative impacts an approach could have on a process or system before making any decisions - ultimately preparing them for cost-benefit analysis and systems thinking often needed when working with chemistry outside of academics.

3.4 Tracing Pathways of Industrial Processes

With flow diagrams, students practice logically and visually through the progression of chemical reactions. For example, the diagram on page 11 is about ammonia and carbon dioxide recycling has the Solvay process. It gives students visual representations of complex systems. It can be challenging to critically examine the inputs and outputs at each step of a multi-step process like the Solvay one shown on page 11. However, it develops critical thinking skills needed to analyze complex sequences of reactions, understand how individual chemical processes integrate into larger systems and deconstruct the logic behind complex chemical processes and industrial systems.

3.5 Comparing Related Concepts

At certain points in the textbook, it critically inspects related chemistry concepts and industrial techniques. On page 15, a detailed comparison of natural vs chemical fertilizers states that natural fertilizers "improve the soil condition" and "do not damage the soil," while chemical fertilizers "release the nutrients very fastly" but "effects are short-lived." Thinking about similarities and differences of similar ideas drives critical thinking skills in students. In comparing natural and synthetic fertilizers, students must analyze the chemical and physical properties of each type to understand their effects on soil, crops, and surroundings. For example, students should reason that the greater water retention from natural fertilizers is due to their organic matter content, while the faster nutrient release for synthetic stems from their simple ionic forms. Asking them to do this work frequently helps them gain experience in identifying key characteristics of substances or processes. From there they can practice using those characteristics to determine strengths, limitations, and situational suitability. Comparing also builds muscle in critical thinking when it comes to using chemical principles for explaining different real-world impacts and outcomes.

3.6 Emphasis On Chemical Reasoning

Questions throughout the textbook always leave no stone unturned as they constantly challenge students' ability to reason through underlying logic for chemical processes. Instead of asking yes-or-no questions, they often ask students to deeply examine and explain why something happens with a given concept. On page 12 it asks, *"Why only NaHCO3 precipitates when CO2 is passed through the ammonical brine?"* To answer correctly students, need to apply solubility knowing that NaHCO3 is least soluble so it will be first to precipitate. Additionally, students should evaluate how ammonia recycling affects the equilibrium of reaction systems. This way, they can develop a habit of conducting careful analyses to understand intricate systems and describe mechanisms that dictate behavior. It will help them move from surface-level knowledge to a more fundamental grasp of chemical phenomena by asking "why" and "how". Such questions encourage critical thinking skills required for questioning, exploring, and logically explaining chemistry concepts.

4. Discussion

Keeping in view the current analysis, the previous studies explored that practical applications and problem-solving techniques are significant in science education (Danczak et al., 2017; Yoon et al., 2014). The current textbook of Chemistry connects chemistry concepts to industrial processes as it requires students to analyze and assess relevance or implications in those contexts. This approach is supported by Nagarajan and Overton (2019), who found that putting chemistry promotes critical thinking and problem-solving skills. This textbook uses open-ended questions to test how well the reader understands and synthesizes information. Gupta et al. (2015) found that inquiry-based instruction makes students a lot better at thinking critically. On the other hand, Vieira et al. (2011) state that explicit teaching of critical thinking should be included in all science education curriculums. Upahi and Ramnarain (2019) also agree with this sentiment and go on to demonstrate that real-life examples are best for building these skills; they even suggest using flow diagrams to show you what they mean. Lastly, Yaniawati et al. (2020) findings in 2020 observed that a mind attuned to the complexities of comparing similar concepts can help students develop an analytical mindset. However, there are areas the research team wants to improve on. Abrami et al. (2015) discovered that more explicit instruction on fundamental thinking strategies and inquiry-based activities would go beyond boosting analytical skills.

5. Conclusion

The development of critical thinking within science students is a crucial part of teaching. This study focused on how to foster critical thinking towards secondary school science students through the use of chemistry. Qualitative content analysis was conducted on the Chemistry grade X book (2020) to find any strategies that might have contributed to the development of these skills among secondary school science students. The same approach was used for this analysis, and as a result, several themes were explored. These themes included connecting concepts to real-world scenarios, open-ended questions that needed analysis, describing pros and cons for each situation, following pathways for industrial processes, comparing similar concepts, and an emphasis on chemical reasoning. Abstract ideas can be hard for students to grasp sometimes but giving them a practical scenario that they can apply their knowledge to helps further develop their brain power into higher order thinking skills such as analysis and synthesis. By doing this it helps them understand why chemistry is important in their everyday life and it will teach them how to solve problems when applied to real situations. The textbooks' effectiveness does not stop there though as it is when addressing specific brand-new concepts that its true potential begins to shine through. Asking open-ended questions like “why” or “how” a great job of is especially weeding out people who just memorize information only to spit it back up later without really understanding what’s going on beneath the surface.

A great method for thinking critically is by comparing similar substances or processes. By doing so, different perspectives are introduced, and students can make decisions based on the pros and cons of each. Impulsive choices with limited knowledge made using one approach alone are not recommended. But before any comparisons can be made, students need a basic understanding of what they are looking at. So, we trace pathways for industrial processes to guide our readers through every step involved in production. Once they understand how chemical principles are interconnected with practical applications at work, all the moving parts become clear, and evaluating efficiency becomes easier. If you want to consider changes or improve future practices from multiple angles of judgment given your newfound broad knowledge of related topics that we provide within this book, assessing sustainability is also simplified. In addition to offering many ways to identify similarities along different aspects of chemistry, we also help sharpen your student's ability to categorize ideas and conceptualize connections between them all which is crucial in breaking down complex systems. With these skills developed, engaging in problem-solving, logical thinking, and evidence-based arguments becomes easier too which will enable them to make their sound judgments on complex chemical systems as well as other topics later in life. Many themes like these contribute towards the development of critical thinking skills but teachers have an important part to play in this process too do not forget! Although there is no denying that the book offers lots of value, just teaching its contents once isn't enough. It is recommended that explicit instructions be given, and case studies be repeated multiple times to maximize the potential benefits of the textbook's content.

5.1 Recommendations

Following are some recommendations based on the findings of the current document analysis:

- Include clear step-by-step instructions within the textbook regarding critical thinking strategies to teach the students how to apply these skills to solve problems.
- Introduce more hands-on activities where students can actively engage themselves in scientific processes like generating hypotheses or analyzing data.
- Enhance visual representations within the textbook so it is easier for students to follow along with calculations.
- Encourage a collaborative learning environment with classroom discussions or group projects.

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