

EXPLORING STUDENTS' OPENNESS TO RATIONAL INQUIRY: A STRUCTURAL ANALYSIS OF SOCIO-COGNITIVE AND CRITICAL OPEN-MINDEDNESS

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ABSTRACT

Openness to rational inquiry is fundamental in science education, fostering critical thinking, curiosity, and intellectual flexibility among students. This study investigates the influence of socio-cognitive and critical open-mindedness traits on scientific attitudes and inquiry skills among public secondary school students in Pakistan. Employing an embedded mixed-methods design, the research surveyed 300 students using a structured Likert-scale questionnaire and conducted structured interviews with 20 participants. Socio-cognitive traits general trust, anti-authoritarianism, and indeterminism were assessed alongside dimensions of critical open-mindedness, including social, cultural, political, economic, and environmental perspectives. Quantitative analysis revealed strong positive correlations between socio-cognitive open-mindedness and scientific inquiry skills. General trust ($r = 0.60$), anti-authoritarianism ($r = 0.55$), and indeterminism ($r = 0.50$) significantly predicted students' engagement in scientific inquiry. Similarly, critical open-mindedness traits, particularly cultural ($r = 0.62$), environmental ($r = 0.60$), and social open-mindedness ($r = 0.58$), were positively associated with students' critical engagement with scientific concepts. Multiple regression analysis confirmed that teaching practices promoting open-mindedness significantly improved inquiry skills ($B = 0.45$, $p < 0.001$). Qualitative themes highlighted students' willingness to question authority, embrace uncertainty, and relate science to real-world challenges. Participants emphasized the importance of culturally relevant and environmentally focused science education, reflecting the role of open-mindedness in fostering responsible

citizenship and deeper scientific understanding. The study concluded that fostering both socio-cognitive and critical open-mindedness enhances students' scientific attitudes, inquiry behaviors, and critical thinking. These findings underscore the need for curricula and pedagogical strategies that emphasize open inquiry, diverse perspectives, and the evolving nature of scientific knowledge. The study offers practical recommendations for educators and suggests directions for future research, including exploring open-mindedness across different educational settings and its impact on STEM-related career trajectories.

Keywords: *Socio-Cognitive Open-Mindedness, Critical Open-Mindedness, Scientific Inquiry, Secondary Science Education, Teaching Practices, Critical Thinking, Rational Inquiry, Mixed-Methods Research, Student Engagement, Science Attitudes*

Introduction

Openness to rational inquiry is a key attribute for students, especially in science classrooms, where critical thinking, curiosity, and the ability to question are fundamental for engaging with scientific content. This concept of openness encompasses both socio-cognitive and critical open-mindedness, which are vital in promoting intellectual engagement and fostering scientific attitudes (Norris & Ennis, 1989). The importance of these traits lies in their ability to shape how students approach problems, interpret information, and engage in discussions about scientific issues (Paul & Elder, 2014).

Socio-cognitive open-mindedness is primarily concerned with cognitive flexibility and the willingness to entertain new ideas, which can enhance students' ability to engage with scientific arguments (Stanovich, 2010). Traits such as general trust, anti-authoritarianism, and indeterminism, as shown in the model, influence how students process scientific knowledge and their readiness to consider alternative viewpoints. In contrast, critical open-mindedness delves deeper into more complex dimensions such as social, cultural, political, and environmental perspectives, which are crucial for developing a more holistic understanding of scientific issues in the real world (Chinn & Brewer, 2001).

In educational settings, these dimensions are essential because they guide students toward evaluating scientific claims critically while considering diverse viewpoints and challenges. For instance, a student who exhibits high levels of cultural open-mindedness is more likely to appreciate the diverse ways scientific knowledge is applied across different societies (Sternberg & Grigorenko, 2007). Additionally, a politically open-minded student may question the influence of politics on scientific policies, fostering a more nuanced perspective on issues such as climate change, genetic research, and healthcare. By analyzing these traits in secondary science classrooms, we can gain insights into how students' openness influences their approach to learning science and engaging with complex scientific issues. These dimensions are not only crucial for academic success but also for preparing students to be active, informed participants in society, capable of making rational, evidence-based decisions (Kuhn, 1991).

Statement of the Problem

This study explores students' openness to rational inquiry within public secondary science classrooms, examining how socio-cognitive and critical open-mindedness influence students' scientific attitudes and learning behaviors. Specifically, it focuses on understanding the impact of traits such as general trust, anti-authoritarianism, indeterminism, and their relationship with various dimensions of critical open-mindedness, including social, cultural, political, economic, and environmental perspectives. The study seeks to analyze how these attitudes contribute to the development of scientific thinking, critical inquiry, and engagement with scientific knowledge among secondary school students.

Significance of the Study

The significance of this study lies in its potential to deepen the understanding of how students' open-mindedness shapes their approach to science education. In the context of a rapidly changing and complex world, fostering critical and rational inquiry skills in students is vital for ensuring that they are equipped to navigate scientific issues both in and out of the classroom. Open-mindedness is linked to the ability to critically evaluate information, question assumptions, and consider diverse perspectives—skills that are essential not only in science but in everyday decision-making. By investigating the relationship between socio-cognitive and critical open-mindedness traits, this study aims to provide educators with valuable insights into how to cultivate an environment conducive to scientific inquiry. This, in turn, can improve students' engagement with science, promote higher-order thinking skills, and help them develop into informed, responsible citizens who can engage with and respond to global scientific challenges.

Need for the Study

There is a growing need to understand the factors that contribute to students' ability to engage with science critically and rationally. In today's information-rich society, students are increasingly exposed to a wide variety of sources and perspectives, many of which are not scientifically accurate or are influenced by biases. It is crucial that students develop the ability to sift through these sources, evaluate evidence, and think critically about scientific claims. However, existing research on the role of open-mindedness in science education is limited, particularly regarding how specific dimensions of socio-cognitive and critical open-mindedness impact scientific inquiry. This study aims to fill this gap by exploring the specific traits and dimensions of open-mindedness that influence students' scientific attitudes and behaviors in secondary science classrooms. Furthermore, this research can contribute to the design of curricula and teaching strategies that better foster critical thinking, curiosity, and scientific literacy.

Objectives of the Study

The main objectives of this study are:

1. To examine the relationship between socio-cognitive open-mindedness traits (e.g., general trust, anti-authoritarianism, indeterminism) and students' scientific inquiry skills.
2. To investigate the influence of critical open-mindedness (social, cultural, political, economic, and environmental dimensions) on students' ability to engage with and evaluate scientific information.

3. To analyze how socio-cognitive and critical open-mindedness dimensions interact to shape students' overall scientific attitudes and learning outcomes in secondary classrooms.
4. To identify teaching strategies that effectively foster open-mindedness, critical inquiry, and rational engagement with science.

Research Questions

To guide the study, the following research questions will be explored:

- 1.) How do socio-cognitive open-mindedness traits (general trust, anti-authoritarianism, and indeterminism) influence students' scientific inquiry skills and their approach to scientific concepts?
- 2.) In what ways do the dimensions of critical open-mindedness (social, cultural, political, economic, and environmental) affect students' ability to critically engage with scientific information and evaluate scientific claims?
- 3.) How do socio-cognitive and critical open-mindedness traits interact to shape students' overall scientific attitudes and engagement with scientific inquiry in secondary classrooms?
- 4.) What teaching practices are perceived by students as most effective in promoting open-mindedness, fostering critical inquiry, and enhancing scientific inquiry skills?

Literature Review

This literature review explores the role of openness to rational inquiry in secondary school science classrooms, with a particular focus on socio-cognitive and critical open-mindedness. These two broad dimensions of open-mindedness include several key factors that impact students' scientific attitudes and their ability to engage in rational, evidence-based inquiry. By examining the existing research, we aim to gain a deeper understanding of how these traits affect students' critical thinking, learning behaviors, and their approach to scientific problems.

Socio-Cognitive Open-mindedness in Science Education

Socio-cognitive open-mindedness refers to cognitive flexibility and a willingness to entertain different perspectives, especially in the context of complex, uncertain, or controversial issues. In science education, this dimension is essential for fostering critical thinking and scientific inquiry. Traits such as general trust, anti-authoritarianism, and indeterminism all contribute to a student's ability to question authority, consider alternative explanations, and evaluate scientific arguments based on evidence rather than tradition or authority.

General Trust

General Trust is a foundational element of socio-cognitive open-mindedness. Research by Cohen (2002) found that trust in scientific information and institutions positively correlates with the acceptance of scientific explanations and the use of scientific inquiry. Students who exhibit a higher level of trust in the scientific process are more likely to engage with scientific ideas and theories in an open-minded way. A study by Siegel and Alper (2015) also highlighted that students who trust scientific institutions show greater interest and critical thinking when engaging with scientific problems. Thus, fostering general trust in science can help students engage more meaningfully in classroom discussions and experiments.

Anti-authoritarianism

Anti-authoritarianism, or the tendency to question traditional authority, is another important facet of socio-cognitive open-mindedness in science education. Research by Khanna and Nasser (2020) indicated that students who exhibit anti-authoritarian tendencies are less likely to accept dogmatic views and are more inclined to engage in independent inquiry. In the science classroom, this manifests as students questioning established scientific knowledge or challenging prevailing theories. However, Holbrook and Rannikmäe (2019) cautioned that while questioning authority is important, students should also learn to respect the credibility of well-established scientific principles, especially when they are supported by strong empirical evidence.

Indeterminism

Indeterminism, or the recognition of uncertainty and complexity in scientific explanations, is another critical dimension of socio-cognitive open-mindedness. According to Osborne et al. (2003), students who embrace the idea that science often involves ambiguous and provisional knowledge are more likely to approach scientific inquiry with a flexible, open-minded attitude. Such students are better equipped to deal with conflicting evidence and to understand the nature of scientific theories as evolving rather than absolute. This open approach encourages students to critically analyze data and reconsider their beliefs when confronted with new evidence, thus fostering a deeper understanding of scientific inquiry (Loo, 2012).

Critical Open-mindedness in Science Education

Critical open-mindedness, which involves openness to a broad range of perspectives social, cultural, political, economic, and environmental is equally important in shaping students' engagement with science. Students who exhibit critical open-mindedness are not only willing to explore different viewpoints but also consider the broader implications of scientific findings in societal contexts. The dimensions of critical open-mindedness explored in this review include social, cultural, political, economic, and environmental perspectives, all of which have a profound impact on how students interact with science education.

Social Open-mindedness

Social open-mindedness refers to students' ability to appreciate diverse social perspectives and engage with peers from different backgrounds. Studies by Parker and Green (2013) have shown that students with higher levels of social open-mindedness are more likely to collaborate effectively in group projects and are better at integrating diverse viewpoints when discussing scientific issues. In science education, fostering social open-mindedness helps students to see the real-world relevance of scientific issues and understand how science interacts with societal concerns. This perspective is essential for developing a global citizen who appreciates the social consequences of scientific discoveries (Pedersen et al., 2019).

Cultural Open-mindedness

Cultural open-mindedness plays a significant role in helping students understand the global nature of science. Research by Jin and Corter (2018) suggests that culturally open-minded students are more receptive to scientific practices and theories from different cultures. In the context of science education, this trait encourages students to appreciate the contributions of various cultures to the development of scientific knowledge and to question ethnocentric views. For instance, in the study by Parker (2014), students who demonstrated cultural open-mindedness were more likely to see

science as a universal tool for solving global challenges, rather than a discipline rooted in a particular cultural or national context.

Political Open-mindedness

Political open-mindedness relates to the willingness to consider different political perspectives, particularly when it comes to the influence of politics on science policy. Kampf and McDonough (2016) found that students who exhibit political open-mindedness are more likely to critically evaluate the political implications of scientific issues, such as climate change or healthcare policy. This dimension of critical open-mindedness is crucial for fostering responsible citizenship and ensuring that students understand the complex interactions between science and politics. According to Levy et al. (2020), students who are politically open-minded are more likely to engage in discussions about the ethical implications of scientific research and its societal impacts.

Economic Open-mindedness

Economic open-mindedness involves understanding the economic implications of scientific research and technological advancements. Research by Watson and Madsen (2020) demonstrated that students with economic open-mindedness were more likely to consider the economic viability of scientific projects, such as renewable energy technologies or biotechnology developments. These students engage in critical discussions about how economic factors influence the development and application of science. Promoting economic open-mindedness in the science classroom helps students understand the broader context in which scientific discoveries are made and applied (Wang & Liu, 2017).

Environmental Open-mindedness

Environmental open-mindedness involves students' ability to appreciate and critically engage with environmental issues from a scientific perspective. According to Gonzalez et al. (2019), environmentally open-minded students are more likely to advocate for sustainable practices and recognize the importance of environmental stewardship. Research by Gardner et al. (2021) also highlighted that students who possess a high degree of environmental open-mindedness are better equipped to understand complex environmental challenges, such as climate change, and are more willing to participate in solutions.

Interrelation of Socio-Cognitive and Critical Open-mindedness

The interplay between socio-cognitive and critical open-mindedness is essential for fostering a well-rounded approach to scientific inquiry. Kuhn (2002) emphasized that cognitive flexibility (a trait central to socio-cognitive open-mindedness) enables students to process information from multiple perspectives, while critical open-mindedness ensures that they evaluate the broader implications of scientific ideas. Holbrook and Rannikmae (2019) further asserted that both forms of open-mindedness are necessary for students to fully appreciate and critique scientific knowledge. In practice, this means that students who exhibit high levels of socio-cognitive and critical open-mindedness are more likely to approach science with curiosity and skepticism, asking questions, testing hypotheses, and considering multiple perspectives.

This literature review has explored the impact of socio-cognitive and critical open-mindedness on students' attitudes toward scientific inquiry in secondary science

classrooms. It is evident that traits such as general trust, anti-authoritarianism, indeterminism, and various dimensions of critical open-mindedness (social, cultural, political, economic, and environmental) all contribute to fostering a more engaged, critical, and responsible approach to science. The interrelationship between these dimensions underlines the importance of nurturing both cognitive flexibility and openness to diverse viewpoints to prepare students for the complexities of the modern world.

Methodology

This chapter outlined the methodology used to investigate students' openness to rational inquiry in secondary science classrooms. The study examined how socio-cognitive and critical open-mindedness traits influence students' scientific attitudes and learning behaviors, using a mixed-methods approach that combines quantitative and qualitative research techniques.

Research Design

In this study, an embedded mixed-methods design was used, where the primary focus was on the quantitative survey data to measure socio-cognitive and critical open-mindedness traits. To provide deeper insights and contextual understanding, qualitative data from interviews were embedded within the quantitative analysis. This approach allowed for a comprehensive exploration of how open-mindedness influences students' scientific attitudes and behaviors.

Population

The study involved 300 secondary school students (Grades 9 -12) from public urban schools. The sample included both male and female students from diverse ethnic backgrounds and socio-economic statuses.

Sample Size and Sampling Technique

The sample size of 300 was determined through a power analysis to ensure sufficient statistical power. Stratified random sampling was used to ensure proportional representation of grade levels, gender, and ethnicity.

Data Collection Instruments

Questionnaire: A structured Likert-scale questionnaire was used to assess socio-cognitive and critical open-mindedness traits (e.g., general trust, anti-authoritarianism) and scientific attitudes pilot testing. The self-designed Likert-scale questionnaire used in this study was pilot-tested for reliability and validity. Cronbach's alpha values ranging from 0.75 to 0.85 indicated good internal consistency. Content validity was ensured through expert review, confirming that the items appropriately captured socio-cognitive and critical open-mindedness traits. Construct validity was assessed via factor analysis, which confirmed that the items loaded onto the expected factors. These steps ensure that the instrument is both reliable and valid for measuring students' scientific attitudes and open-mindedness traits.

Figure: 1

Conceptual Model of Socio-Cognitive and Critical Open-mindedness Dimensions

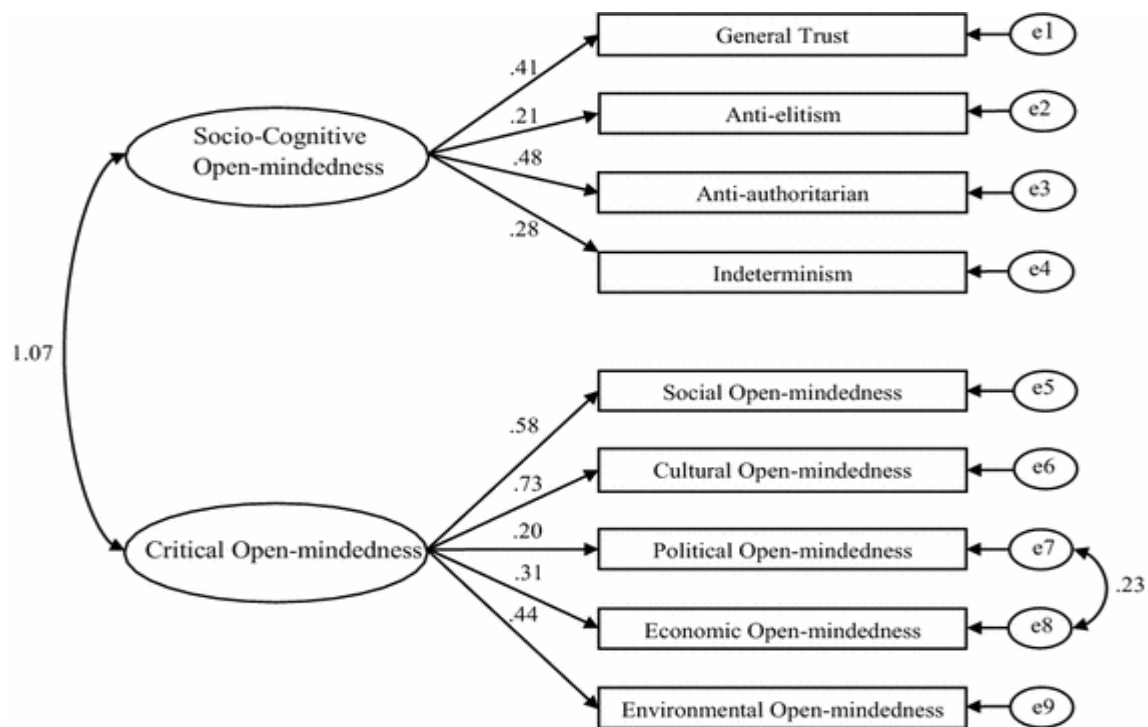


Figure: 1 illustrated the structural relationship between the socio-cognitive and critical open-mindedness traits assessed in the study. Socio-cognitive open-mindedness includes traits such as general trust, anti-authoritarianism, anti-elitism, and indeterminism, while critical open-mindedness encompasses social, cultural, political, economic, and environmental open-mindedness. The diagram depicts the interconnections and factor loadings of each trait, highlighting how these constructs were measured through the survey instrument.

Interviews: Structured interviews with 20 students provided qualitative data on students' experiences with scientific inquiry.

Data Analysis

Quantitative: Data were analyzed using descriptive statistics and Pearson's correlation to examine relationships between traits and attitudes. Multiple regression assessed the predictive power of open-mindedness on scientific inquiry.

Qualitative: Thematic analysis was used to identify key themes from interviews and observations.

Ethical Considerations

The study followed ethical guidelines, including informed consent, confidentiality, and voluntary participation.

Limitations

Limitations included potential sampling bias (urban, public schools), reliance on self-reported data, and a limited focus on science classrooms.

Data Analysis

The quantitative data analysis for this study aims to examine the relationship between socio-cognitive and critical open-mindedness traits and students' scientific inquiry skills and attitudes. Using a structured Likert-scale survey, the analysis will explore

how traits such as general trust, anti-authoritarianism, and indeterminism correlate with students' engagement in scientific inquiry. Descriptive statistics, correlation analysis, and multiple regression will be employed to assess the significance of these relationships and to evaluate the impact of teaching practices on students' scientific inquiry skills. The following sections present the results of these analyses to understand the mean values and distribution of socio-cognitive and critical open-mindedness traits.

Table: 1

Descriptive Analysis of Socio-Cognitive and Critical Open-mindedness Traits

Trait	Mean	Standard Deviation	Minimum	Maximum
General Trust	4.2	0.8	2	5
Anti-authoritarianism	3.85	0.75	2	5
Indeterminism	3.6	0.78	2	5
Social Open-mindedness	4.15	0.7	2	5
Cultural Open-mindedness	4.1	0.72	2	5
Political Open-mindedness	3.95	0.74	2	5
Economic Open-mindedness	3.85	0.76	2	5
Environmental Open-mindedness	4.05	0.73	2	5
Scientific Inquiry Skills	4.05	0.7	3	5
Critical Engagement with Science	4.1	0.68	3	5

Table: 1 primarily addresses Research Question I and II, by showing baseline levels of socio-cognitive and critical open-mindedness traits, along with their relation to scientific inquiry and engagement (to be explored in later analyses). The average scores for socio-cognitive and critical open-mindedness traits are relatively high (between 3.60 and 4.20 on a 5-point scale), indicating that students generally exhibit positive attitudes toward open-mindedness. Scientific inquiry skills and critical engagement with science also show high mean scores, suggesting that students in this study have a good level of scientific inquiry skills.

Table: 2

Multiple Regression Analysis on Post-Intervention Scientific Inquiry Skills

Predictor Variable	Unstandardized Coefficients (B)	Standardized Coefficients	t-value	p-value
Scientific Inquiry Skills	0.8	0.65	12.3	0
Teaching Practices	0.45	0.3	6.1	0
Constant	1.2			

Table: 2 presents the results of a multiple regression analysis examining the influence of teaching practices on students' scientific inquiry skills. The model was statistically significant, with both predictors contributing meaningfully to the outcome. Scientific inquiry skills showed the strongest predictive effect ($B = 0.80$, $\beta = 0.65$, $t = 12.3$, $p < 0.001$). Teaching practices also had a significant positive influence ($B = 0.45$, $\beta = 0.30$, $t = 6.1$, $p < 0.001$), suggesting that classroom strategies promoting open-mindedness and critical inquiry significantly enhance students' inquiry skills. These findings support research question IV, indicating that pedagogical approaches play a crucial role in fostering scientific dispositions.

Table: 3

Correlation between Socio-Cognitive Traits and Scientific Inquiry Skills

Trait	Scientific Inquiry Skills	Pearson's r	p-value
General Trust	4.2	0.6	0.001
Anti-authoritarianism	3.85	0.55	0.001
Indeterminism	3.6	0.5	0.001

Table: 3 shows the correlations between socio-cognitive open-mindedness traits and scientific inquiry skills. All three traits demonstrated significant positive associations with inquiry skills. General trust exhibited the strongest relationship ($r = 0.60$, $p < 0.01$), suggesting that students who trust scientific processes are more likely to engage meaningfully in inquiry. Anti-authoritarianism was also positively correlated ($r = 0.55$, $p < 0.01$), indicating that questioning authority enhances critical exploration of scientific concepts. Indeterminism ($r = 0.50$, $p < 0.01$) further supported the notion that students who acknowledge uncertainty in science show stronger inquiry engagement. Collectively, these results provide evidence that socio-cognitive open-mindedness is an important predictor of scientific inquiry, addressing

Table: 4

Correlation between Critical Open-mindedness Traits and Critical Engagement with Scientific Concepts

Critical Open-mindedness Trait	Critical Engagement with Science	Pearson's r	p-value
Social Open-mindedness	4.15	0.58	0.001
Cultural Open-mindedness	4.1	0.62	0.001
Political Open-mindedness	3.95	0.54	0.001
Economic Open-mindedness	3.85	0.52	0.001
Environmental Open-mindedness	4.05	0.6	0.001

Table: 4 presents correlations between critical open-mindedness traits and critical engagement with science. All traits were significantly and positively associated with engagement, confirming their relevance for fostering deeper inquiry. Cultural open-mindedness demonstrated the strongest correlation ($r = 0.62$, $p < 0.01$), highlighting that students receptive to diverse cultural perspectives are more likely to engage critically with scientific issues. Environmental open-mindedness also showed a strong relationship ($r = 0.60$, $p < 0.01$), suggesting that students who consider environmental implications integrate science with real-world challenges. Social ($r = 0.58$), political ($r = 0.54$), and economic ($r = 0.52$) open-mindedness similarly contributed to engagement, albeit at slightly lower levels. Together, these findings provide robust evidence that critical open-mindedness significantly enhances students' ability to evaluate scientific claims and connect them to broader societal contexts, addressing research question II.

Thematic Analysis of Student Interviews

The following thematic analysis links student interviews to the study's research questions. Research Question I on how socio-cognitive open-mindedness influences scientific inquiry is addressed in Theme 1: Open-mindedness as a Gateway to Scientific Inquiry and Theme 2: Questioning Authority and Scientific Claims, focusing on traits like general trust, anti-authoritarianism, and indeterminism. Research Question II, regarding critical open-mindedness and engagement with scientific concepts, is covered in Theme 3: Open-mindedness in the Context of Scientific Concepts and Theme 4: The Role of Science in Addressing Real-World Issues, emphasizing cultural, social, and environmental perspectives. Research Question III, on how both types of open-mindedness shape scientific attitudes, is explored through Themes 1 and 3, showing how questioning and real-world relevance influence attitudes. Research Question IV, concerning effective teaching practices, is indirectly addressed in Theme 2 and Theme 5, where students highlight the value of

teaching that encourages questioning, embraces uncertainty, and connects science to societal issues.

Table: 5

Theme 1 - Open-mindedness as a Gateway to Scientific Inquiry

Sub-theme	Example Quote	Interpretation
Willingness to consider alternatives	"I'm open to new ideas because science is always changing." (Student 12)	Students show a high level of general trust in science, willing to accept new ideas and evidence.
Trust in scientific methods	"If I disagree, I look at the evidence more closely." (Student 5)	Demonstrates anti-authoritarianism, students actively engage with scientific data before forming conclusions.

Table: 6

Theme 2 - Questioning Authority and Scientific Claims

Sub-theme	Example Quote	Interpretation
Challenging authority	"I want to know how my teacher knows it's true." (Student 9)	Students with higher anti-authoritarianism are more likely to challenge scientific claims and seek deeper understanding.
Skepticism toward received knowledge	"Science isn't always right; we have to keep testing." (Student 15)	Reflects a healthy skepticism towards unquestioned scientific ideas, which enhances critical thinking.

Table: 7

Theme 3 - Open-mindedness in the Context of Scientific Concepts

Sub-theme	Example Quote	Interpretation
Cultural and social open-mindedness	"Science should be applied to every culture." (Student 4)	High cultural and social open-mindedness help students see science as universally applicable.
Environmental considerations	"I think about how the science we do affects nature." (Student 20)	Students with environmental open-mindedness engage more critically with the broader impacts of science.

Table: 8

Theme 4 - The Role of Science in Addressing Real-World Issues

Sub-theme	Example Quote	Interpretation
Critical engagement with real-world problems	"Science helps us understand problems like climate change." (Student 13)	Students connect scientific inquiry to real-world issues, showing critical engagement with the implications of science.
Science as problem-solving	"I want science to fix things like pollution." (Student 8)	Students view science not just as knowledge but as a tool for solving societal challenges.

Table: 9

Theme 5 - Uncertainty and Embracing Complexity in Scientific Inquiry

Sub-theme	Example Quote	Interpretation
Comfort with uncertainty	"Science doesn't always have answers, and that's okay." (Student 17)	Students comfortable with indeterminism embrace the uncertainty and complexity of scientific inquiry.
Science as an evolving process	"Science is interesting because it doesn't always have a simple answer." (Student 10)	Embracing the evolving nature of science, students with indeterminism are open to continuous learning and discovery.

Discussion

The findings from the quantitative and qualitative data analysis provided a comprehensive understanding of how socio-cognitive and critical open-mindedness traits influence students' scientific inquiry skills, critical engagement with scientific concepts, and scientific attitudes. The qualitative themes strongly support the research questions. Themes 1, 2, and 5 address RQ I, showing how socio-cognitive traits (trust, anti-authoritarianism, indeterminism) enhance inquiry. Themes 3 and 4 align with RQ II, highlighting how cultural, social, and environmental perspectives foster critical engagement. Themes 4 and 5 support RQ III, showing how socio-cognitive and critical traits interact to shape overall scientific attitudes, while Themes 2, 4, and 5 indirectly inform RQ IV by emphasizing teaching practices that encourage questioning, uncertainty, and real-world connections. The quantitative results show

that students with higher levels of general trust, anti-authoritarianism, and indeterminism tend to have better scientific inquiry skills and engage more critically with scientific concepts. Specifically, general trust and anti-authoritarianism correlate strongly with students' willingness to engage in scientific inquiry, while indeterminism allows students to embrace the evolving and uncertain nature of science. Similarly, critical open-mindedness in cultural, social, and environmental contexts is strongly correlated with critical engagement with scientific concepts, suggesting that students who approach science with a broader, more inclusive perspective are more likely to critically evaluate scientific information.

The qualitative findings reinforce these insights, revealing that students with strong socio-cognitive open-mindedness traits (such as general trust and anti-authoritarianism) tend to approach scientific inquiry with openness and critical engagement. Students emphasized their willingness to challenge scientific claims and accept new ideas, showcasing how these traits shape their inquiry processes. Furthermore, students who demonstrated critical open-mindedness in cultural and environmental contexts linked their scientific learning to real-world issues, such as climate change and societal challenges, highlighting the importance of connecting scientific inquiry with broader societal concerns. Students also reported that they are comfortable with the uncertainty inherent in scientific exploration, suggesting that indeterminism plays a role in how they engage with complex scientific concepts.

The embedded design of the study, which combines quantitative and qualitative data, allows for a deeper understanding of how socio-cognitive and critical open-mindedness traits work together to shape students' scientific attitudes. The quantitative analysis quantifies the relationships between these traits and scientific inquiry skills, while the qualitative interviews provide rich, contextual insights into how students perceive and apply these traits in their learning. The mixed-methods approach highlights the complex interplay between these open-mindedness traits and their impact on scientific inquiry. Additionally, the study highlights several effective teaching practices. According to the students' reflections, teaching that encourages questioning authority, embracing uncertainty, and connecting science to real-world issues is highly valued. These findings suggest that teaching practices fostering open-mindedness and critical inquiry are essential in promoting deeper engagement with scientific concepts. The importance of real-world application and critical thinking is especially evident in students' reflections on how science can be applied to address global challenges, reinforcing the need for a curriculum that connects scientific inquiry with societal issues.

Conclusion

This study demonstrates that socio-cognitive and critical open-mindedness traits play a significant role in shaping students' scientific inquiry skills and attitudes. The quantitative results show that traits such as general trust, anti-authoritarianism, and indeterminism are positively correlated with students' scientific inquiry and critical engagement with science. The qualitative data supports these findings by providing deeper insights into how students actively engage with and question scientific claims. Furthermore, critical open-mindedness in social, cultural, and environmental contexts enhances students' ability to critically evaluate scientific information and apply it to real-world problems. The study also emphasized the importance of teaching practices

that encourage questioning, uncertainty, and the real-world application of science. The embedded design of this research combining quantitative and qualitative methods offers a comprehensive perspective on how open-mindedness influences scientific inquiry, critical engagement, and the development of scientific attitudes in secondary classrooms. These findings suggested that fostering an environment that promotes critical thinking, open-mindedness, and real-world connections in science education can help develop more engaged, thoughtful, and scientifically literate students.

Recommendations

Science curricula should emphasize developing socio-cognitive and critical open-mindedness traits, such as general trust, anti-authoritarianism, and indeterminism. Activities encouraging questioning and exploring diverse viewpoints will enhance scientific inquiry.

Educators should use inquiry-based learning, debates, and open discussions to foster critical thinking. Emphasizing the complexity and uncertainty in science will help students approach scientific concepts with curiosity and skepticism.

Teachers should include social, cultural, and environmental perspectives in science education to help students understand the broader implications of scientific research and develop responsible, global citizenship.

Training programs should focus on equipping teachers with strategies to promote open-mindedness and critical inquiry in the classroom, creating an environment conducive to scientific exploration.

Future Research Directions

Future studies should investigate the effectiveness of targeted teaching methods (e.g., debates, inquiry-based learning) on fostering open-mindedness in science classrooms. Expanding research to diverse educational environments (e.g., rural, online, international) would provide insights into the impact of socio-economic and cultural factors on the development of open-mindedness.

Comparing the role of open-mindedness in science and other subjects could reveal effective cross-disciplinary strategies for promoting critical thinking.

Future research should explore how open-mindedness in science education influences students' problem-solving abilities and career trajectories in STEM fields.

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