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Exploration of Student's Critical Thinking Skills in the Context of Chemistry Based on the Nature of Science

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Abstract

Understanding the Nature of Science (NoS) could help improve thinking and reasoning skills. Students could use their critical thinking (CT) skills to help themselves in solving problems. Based on the NoS, this study sought to assess the CT skills of chemistry pre-service teachers at university. This study used a qualitative with a case study as the method. A purposive sampling technique was elaborated to select the research object. The respondents were chemistry students at university. The data sources were open-ended questions and interviews from the NoS questionnaire. The method of data triangulation was employed to conclude the study findings. The results showed that the CT skills possessed by chemistry pre-service teachers: were interpretation skills, inference skills, and self-regulation skills. Those skills were still in the low category. The participants also lacked in explaining, evaluating, and analyzing the students' abilities. Thus, the understanding of NoS informants can be categorized in the transitional cohort. The research findings became the department's input because some students still struggled to analyze NoS aspects in chemistry, especially through each stage of CT skills. Hence, future research is suggested to develop the students' CT skills in applying the NoS aspect in chemistry learning, especially for the pre-service teacher.
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Keywords: chemistry pre-service teacher, critical thinking, nature of science

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1. Introduction

The learning process requires some insights that can support the current era. Boholano (2017) states that 21st century education can provide real concepts and theoretical constructions to increase knowledge, skills, and attitudes built in the education world. In reality, this disruption era involves schools or universities having a skill and teaching with critical thinking (CT), creative thinking, communication, and collaboration, or what is called 4C (Septikasari in Nurfazri, 2022). Meanwhile, this century consists of collaboration, creativity, innovation, critical thinking, problem-solving, and communication skills (Wijaya et al., 2016).

However, one of the 21st century characteristics that chemistry pre-service teachers must possess is the ability to think critically. Students can possess these abilities to support their professional abilities (Sutamrin & Khadijah 2021; Wijaya & Fitriani, 2021). In other words, CT skills also have an important role in chemistry.

Besides, the world of chemistry is part of science and contains facts and laws, and the truth must be proven. These characteristics are part of the (NoS) as knowledge (Monroe et al., 2013). NoS can describe how science works, and researchers (scientists) conduct research (Listiani & Kusuma, 2017). NoS comprises five components: tentative, empirical, scientific theories and laws, imagination, and scientist subjectivity (Chen, 2006; Lederman et al., 2002; Yulita et al., 2019). Chemistry and NoS are a unit that chemistry pre-service teachers must understand, especially as pre-service teachers

(Oliveira & Barufaldi, 2009; Rowe et al., 2015; Yacoubian, 2020). Pre-service chemistry teachers must be able to integrate NoS into chemistry which will be taught to their students. Thus, an understanding of NoS based on chemical knowledge must be well mastered by a pre-service chemistry teacher. On the other hand, CT skills must also be mastered and implemented in every aspect of learning chemistry. Thus, CT skills should be a powerful chant for pre-service teachers in criticizing every characteristic of science that encompasses chemistry.

Regarding CT, Tiruneh et al. (2014) state that CT trains the mind to analyze problems based on relevant questions and information. The important role of CT in the world of chemistry is dealing with the development of science and technology (Kurniawati, 2018) and can be used to solve problems in the surrounding environment (Nugrahaeni et al., 2017). Then, Kartika et al. (2019) explain that as education students who will become educators, these abilities can help make innovations in the learning process.

Furthermore, CT skills have an important role in the world of work. Someone with high-order thinking skills (creative and CT) can help companies solve problems (Widodo et al., 2019). In addition, CT is also needed in activities in society. Students will contribute to society and become part of the community so that CT can be used as a tool for social function. Besides, CT can help a person decide and evaluate both based on individual, social, and political information (Allamnakhrah, 2013). Therefore, CT skills need to be possessed by chemistry pre-service teachers.

NoS and CT skills have become the focus of studies in science education (Bett et al., 2023; Rowe et al., 2015; Sengul, 2019; Verhey, 2006). Both are complementary aspects of building skills and basic knowledge of studying science because presenting a strong foundation regarding NoS positively affects students' ability to think effectively about learning chemistry as a part of science (Verhey, 2006). Also, NoS will allow students to practice solving problems scientifically (Annisa & Listiani, 2017; Imran & Widodo, 2018). Then, Widodo et al. (2019) explained that solving various problems can improve a person's CT ability. This skill aligns with the statement Annisa & Listiani (2017 and Imran & Widodo (2018) that implementing NoS can help improve thinking and reasoning abilities.

On the other hand, chemistry is a branch of science that is complex and abstract; however, in its application, chemistry is very close to everyday life (Kartika et al., 2019). Understanding chemistry requires the ability to connect and transfer concepts; in the process, it stimulates students to have the ability to think (Imaduddin & Haryani, 2019; Kartika et al., 2019). Yulita et al. (2019) state that studying chemistry is also part of science and cannot be separated from understanding the nature of science, in which many scientific problems exist.

Currently, the department of chemistry education at university has implemented a curriculum based on sustainability aspects. This condition prompted the researcher to choose this study: how the curriculum supports the development of sustainable 21st century skills that involves CT skills in chemistry as part of science. Furthermore, students must also be able to analyze the concept of NoS in every chemical context critically. Various studies have proven a close relationship between understanding NoS and CT skills. However, no research specifically measures both in prospective chemistry teacher students in the chemistry education study program at university. Therefore, this study presents to determine the CT skills of chemistry teacher candidates regarding the NoS concept in the chemistry context. Hence, this research is intended to provide valuable information for further curriculum improvement.

2. Research Method

This study aimed to determine the CT skills of chemistry pre-service teachers at UIN Walisongo of Semarang based on the NoS in the chemistry context. This type of research is a qualitative approach with a case study design (Cohen et al., 2018). The case study was chosen because the researcher looked for inferences for curriculum improvement in that major. Informants were taken based on the technique of purposive cluster random sampling (Hutama et al., 2013), where the informants were determined based on the needs of the researchers: The Chemistry Pre-service teachers of UIN Walisongso Semarang who were studying in the 3rd semester of the 2022-2023 academic year, and have taken basic chemistry courses. The questionnaire was distributed to the participants. And then, the researchers received a complete response of 30 answers. Data sources were obtained from the questionnaire and interviews as a research instrument. The research instrument was designed to integrate indicators of CT skills and NoS in the chemistry context adopted from Welter et al. (2023).

The validity of the research data was tested using data triangulation, where researchers compared the results of questionnaires and interviews with journals to obtain valid data. Besides, this questionnaire was chosen because it contains questions that can be applied in chemistry, and the questions given were open-ended. The researcher completely adopted the questionnaire. The questionnaire contained six questions covering aspects of CT, including interpretation, analysis, evaluation, inference, explanation, and self-regulation from Facione (2015) and NoS: tentative, knowledge-based (empirical), law and theory, creativity, and subjectivity and social (See in Table 1). Furthermore, researchers integrated CT skills with NoS understanding and interpreted based on the level of NoS expertise (NoS beliefs) (Welter et al., 2023). The instrument chosen by the researcher was also used as a guide in conducting interviews following the questions in the questionnaire. Thus, analysis was carried out descriptively phenomenologically based on quantitative data from the results of scoring respondents' answers in each indicator.

The analysis included the ability of pre-service teachers in chemistry to explore each aspect of CT and NoS in a chemistry context. The student's answer to the assessment aspect is categorized into three: naive, transitional, and informed (Lampert, 2020; Welter et al., 2023). Students categorized into naive could be identified by a statement if the student did not have a proper CT skill in the NoS of chemistry context.

Meanwhile, students who fell into the naive category could be identified by statements that show misunderstanding in expressing ideas from aspects of CT skills and NoS in a given chemical context. It was included in the transitional criteria. The transitional category was identified with student statements showing the truth in some aspects of CT skills and NoS in a chemical context. Finally, the Informed category was identified through student statements which completely cover aspects of CT skills and NoS in a given chemical context (See Table 1).

Table 1. Integrated Indicator of CT Skills and NoS Aspects and the Category of the Answer

The Assessment Aspect	Category	Indicator of the Assessment Aspect
Interpretation	Naive	Cannot interpret theory and law on empirical data, and cannot convey arguments from the truth of the context under discussion.
	Transitional	Inaccurate in interpreting theory and law on empirical data, and is inflexible and creative in conveying ideas of truth from the context under discussion.
	Informed	Able to fully interpret theories and laws on empirical data and flexibly and creatively convey ideas of truth from the context under discussion.
Analysis	Naive	Neither can find truth nor falsity in the existence of theoretical and legal bases in the empirical data of the context under discussion and cannot explain why it happens.

The Assessment Aspect	Category	Indicator of the Assessment Aspect
	Transitional	inaccurate in evaluating the presence of a theoretical and lawful basis on empirical Data from the context discussed, and does not fully convey the results of the evaluation in the form of flexible and creative ideas.
	Informed	Able to properly evaluate the existence of theoretical and legal basis on empirical data from the context discussed and convey the results of the evaluation in the form of flexible and creative ideas.
Evaluation	Naive	Unable to infer empirical data in the context discussed based on theory or law and unable to explain why.
	Transitional	Inaccurate in evaluating the existence of a theoretical and legal basis on empirical data from the context discussed, and does not fully convey the results of the evaluation in the form of flexible and creative ideas.
	Informed	Able to properly evaluate the existence of theoretical and legal basis on empirical data from the context discussed and convey the results of the evaluation in the form of flexible and creative ideas.
Inference	Naive	Unable to infer empirical data in the context discussed based on theory or law and unable to explain why.
	Transitional	Inaccurate in inferring empirical data in the context discussed based on theory or law, and does not fully convey the results of inference in the form of flexible and creative ideas.
	Informed	Able to make precise references to empirical data in the context discussed based on theory or law and convey the conclusions with flexible and innovative ideas.
Explanation	Naive	Cannot explain the existence of every aspect of the nature of science from the context discussed.
	Transitional	Inaccurate in conveying the reasons for mentioning each aspect of the nature of science from the context discussed.
	Informed	Provide precise and complete explanations for saying every part of the nature of science from the context discussed.
Self-regulation	Naive	Cannot find an answer that does not comply with the rules given.
	Transitional	Less precise in finding discrepancies in responses to the regulations given.
	Informed	Find and provide the right reasons for each answer that is not following the directions given

3. Result and Discussion

This research is a scientific work compiled through the scientific method. Louis Cohen (Cohen et al., 2018) argues that the social sciences are the same as the natural sciences and are concerned with discovering natural and universal laws that govern and determine individual and social behavior. The scientific method in this research is a guideline for conducting research, starting from determining research themes (problem formulation), assumptions on initial findings, validated instruments, researchers, data leverage tools, research implementation through data collection, In-depth interview technique of the informant's NoS probability, analysis of data, the process of systematically searching, compiling data, correlations based on NoS found, and interpretation of data Relationships between NoS domains based on field studies (see Figure 1).

The research begins with determining the formulation of the problem based on an initial study of field conditions (chemistry education students) and a review of the literature related to the focus of the problem. After knowing the main issues, the researcher makes initial assumptions about how the condition of the target sample should be as a limitation when carrying out the research. The next stage is data collection, followed by analysis, and ends with data interpretation.Based on the respondents' answers, it was obtained that most students were in the transitional category in achieving the NoS (Welter et al., 2023). After obtaining the percentage of answers from all respondents, then the researcher, as an expert, conducted structured interviews with the informants.

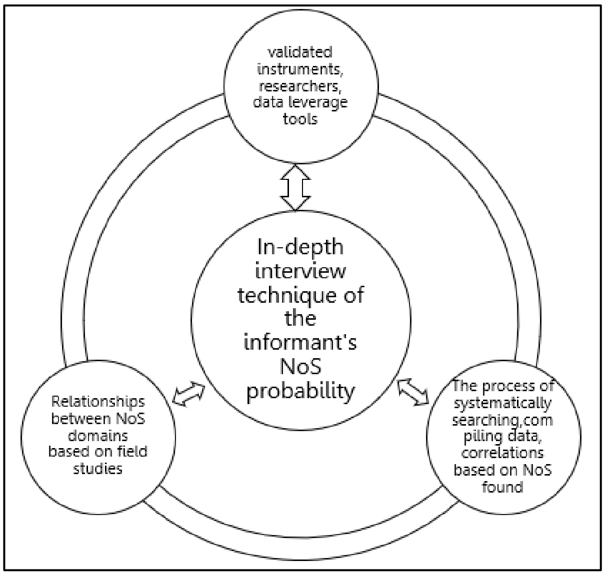

Figure 1. Scientific Method of Scientific Work in this Research

1.1.1. Informed Category

The answers given by the informants at the time of the interview also provided information that the answer followed the expert's answer. The tentative aspect explains that scientific theories would continue to develop the experience refinement. According to the informant's answer to the expert, the informants in this category understood the tentative aspect and could provide appropriate explanations and evidence; then, the informants can be categorized as informed (Lampert, 2020; Welter et al., 2023). Based on the answers given by the informants, students have understood aspects of scientific theory and law by providing answers following expert answers and could provide appropriate explanations and evidence. Thus, informants can be categorized in the category of informed in understanding aspects of scientific theory and law.

1.1.2. Transitional Category

In this category, the informants have understood aspects of scientific theory and law by being able to mention the difference between scientific theory and law, but the informants have not been able to provide evidence or explanations to support their answers. Therefore, the informants are categorized as "Transitional" in understanding scientific theory and law. Furthermore, the informants have provided answers to the questions but have not fully answered the questions in question (Welter et al., 2023). After conducting interviews, the informants provided more detailed answers regarding using scientists' creativity in conducting investigations. The creativity aspect explains that the development of science involves scientific observation. However, developing science also involves the creativity and imagination of scientists (Lederman et al., 2002).

1.1.3. Naive Category

The answers given by the informants in this category at the time of the interview provided information that the answer was not following the expert's answer. The informants tried to answer according to the existing questions, but the answers were not following the context of using scientists' creativity in conducting investigations (Yulita et al., 2019). Moreover, the informants did not yet understand the aspects of creativity that scientists used in conducting investigations. Therefore, the informants can be categorized in the category of naive in understanding the aspect of creativity (Bett et al., 2023).

On the other hand, as the essence of science, NoS includes tentative, knowledge-based (empirical), law and theory, creativity, subjectivity, and social aspects. Consequently, students got difficulty adopting every aspect measured by CT skills in a given chemistry contest. The tentative aspect describes scientific knowledge that can be considered durable and not easily changed (Yulita et al., 2019), but all scientific knowledge is subject to change (Annisa & Listiani, 2017; Imran & Widodo, 2018). Thus, true science will continue to experience development or refinement. Besides, the basic empirical aspect explains that science refers to empirical data and evidence. Even though empirical evidence is used as the main basis, its existence is not interpreted in absolute terms (Yulita et al., 2019). Another aspect that is also considered difficult for students is the aspect of scientific and legal theory.

3.2.1. Interpretation

The ability to interpret in this context means applying concepts derived from Rutherford's experiments in discovering atomic structures. This study found that the informant had not interpreted the questions correctly in the completed questionnaire. After that, the researchers conducted interviews with each informant. The results obtained were different from the results of the questionnaire answers. Informants gave more detailed answers when the interview was conducted. Informants could determine the concepts used in answering these questions: explaining the Rutherford experiment. The following were excerpts from the answers to interviews conducted by researchers and informants.

Based on the interview results, it was explained that the informant had determined the concepts used in solving questions related to the basic empirical aspects. Therefore, the informant could have been able to interpret "Yes". It means that there was development. For example, this electron was discovered by Thomson. At that time, Thomson used a glass tube experiment and then looked at the effect of cathode rays. Then, protons were also using additional experiments; to complement the previous experiments: experiments to study positive particles. After that, for the discovery of this atomic nucleus, there was another developmental experiment by Rutherford that used the scattering of alpha rays by a gold plate.

After knowing the concept used, the informant was expected to be able to carry out an analysis could to solve the problem. However, when answering the questionnaire, the informants did not do any analysis at all. When interviews were conducted, only DH informants could relate theories and provide evidence for the certainty of scientists in putting forward theories.

Interpretive skills can be developed by understanding and expressing the meaning of various experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures, and criteria (Facione, 2015). Based on the research, the informants could not determine the concepts used in answering the questions or describe the meaning clearly and precisely. Then during the interview, the informant could determine the concept used in answering the question. The concept's application in the context of tentative: the advancement of atomic theory. Based on the interview results, the informant could interpret where the informant mentions atomic theory as an example of a concept in answering the tentative aspect. The ability to interpret the problems presented based on the informants' answers to the questionnaire; the informants could have been interpreting questions regarding aspects of scientific theory and law. This finding is indicated by the informants' answers regarding the differences between scientific theories and laws. Meanwhile, the informants' answers to the questionnaire could interpret the questions regarding aspects of creativity. This answer was indicated by the informants' answers regarding the similarities and differences between art and science (Sengul, 2019). Informants responded that scientists used their creativity to develop hypotheses.

3.2.2. Analysis

Analytical skills are the ability to identify the intentions and relationships of actual conclusions among various statements, questions, concepts, descriptions, and other forms of representation (Facione, 2015). This study provides information that the informants have been unable to conduct analytical activities. Informants only provide conclusions without conducting an analysis first. When conducting interviews by asking the same questions, the informants could explain the conclusions drawn by connecting the atomic theories that scientists had put forward. This data proved that the informants have analytical skills that were strengthened during interviews.

Analytical skills also could be seen from the ability of the informant to provide evidence or examples and relate the evidence. When the informant had not been able to perform the analysis, then the informants could provide examples and relate them to their answers when conducting interviews. In the questionnaire given, the informant was unable to carry out the analysis, while in the interviews conducted, the informant was able to provide examples and relate them to the answers given. Informants explain the fairness of the results of different studies. This data could be influenced by various factors, both internally and externally.

Analytical skills felt difficult for most informants; it could be seen from the ability of the informant to provide evidence or examples and relate the evidence (Cavagnetto, 2010). In the questionnaire given, the informant was unable to perform the analysis. Likewise, in the interviews, only some informants could provide examples and relate them to the answers. Most informants could only mention that scientific theories and laws have differences. In other words, students could not provide examples or relate existing theories revealed during the interview. Therefore, the informant had not used his analytical skills to answer questions on scientific theory and law.

3.2.3. Evaluation

Evaluation skills can be achieved if students solve problems according to the context. Based on the answers to the questionnaire, the informants have provided conclusions on the questions but have not fully answered the questions in question. After the interview, the informant gave more detailed answers regarding the tentative aspect. The suitability of the informant in providing answers to the existing questions proved that the informant could evaluate it. Based on the answers to the questionnaire, the informants could not answer according to the questions, while the interviews conducted by the informants were able to evaluate according to the context of the problem. These findings can be seen in the excerpts from the interview answers.

Some informants tried to provide answers to questions but have not fully answered the questions in question. After the interview, the informants gave more detailed answers regarding scientific theory and law. The suitability of the informant in providing answers to the existing questions proves that the informant had the skills to evaluate. However, other informants have tried to answer according to the existing questions, but the answers given did not follow the problem's context.

Evaluation skills could also be achieved if students were not to solve problems according to the existing context (Yacoubian, 2020). Based on the answers to the questionnaires and interviews conducted, the informants could answer according to the questions. Informants could evaluate according to the context of the problem: the subjectivity of scientists in conducting investigations and the factors that influence differences in experimental results. Then, the informant provided an appropriate explanation to support the conclusions that had been presented. Informants had given reasons for the subjectivity of scientists in conducting experiments. The reason was understandable and similar to the expert's answer (Yulita et al., 2019). Therefore, the informants have inference skills in subjectivity and socio-culture.

3.2.4. Inference

Inference skills are the ability to make conclusions based on available information and pay attention to the completion steps. Based on the informants' answers, it was determined that the informants had used their inference skills to solve questions. Informants concluded that the theory could change as discoveries are made. The informant's ability was strengthened after conducting the interview. The informant gave the same answer when the interview was conducted. Inference skills were demonstrated by the informant when answering the questionnaire. Informants concluded that scientists have certainty in putting forward their theories, which their experiments prove. When the interview was conducted, the informant also concluded the same thing. Therefore, the informant has used his inference skills to solve problems in the empirical aspect.

In this case, after being able to make inferences, the informant was required to provide an appropriate explanation in order to support the conclusions that had been presented. Based on the interview, the informants gave reasons for scientists' certainty in proposing theories. The reason was understandable and almost similar to the expert's answer. Inference skills also had been carried out by informants by providing answers about the difference between theory and scientific law. The conclusions given by other informants were also following the conclusions presented by the expert. When the interview was conducted, the informant concluded the same thing. Therefore, the informant used their inference skills to solve problems empirically.

On the other hand, the informants might conclude the differences and similarities between art and science. Also, each informant gave their answer differently. When interviewed about using scientists' creativity in conducting investigations, only one informant had different answers regarding this view (TL informant). TL informants explained that scientists did not use their imaginations when conducting investigations. Inference skills also have been owned by the informant by concluding that the final results obtained in the investigation or research were subjectivity from the scientist himself. Meantime, the informants' conclusions followed the expert explanation (Yulita et al., 2019). Therefore, the informants used their inference skills to solve problems in subjectivity and socio-culture.

3.2.5. Explanation

Explanation skills provide reasons or arguments regarding the answers presented (Facione, 2015). Based on the informant's answer to the questionnaire, the theory might change, according to the DH informant scientists updated the theory to seek knowledge or improve previous findings. This finding proves that the informant gave the right reasons for the answers. In other words, the informants could account for the answers presented.

After being able to make inferences, the informant was required to provide an appropriate explanation to support the conclusions that had been presented. Based on excerpts from interviews conducted by DH researchers and informants, the informants gave reasons for the differences between scientific theories and laws and explained the evidence that supports them. The reason was understandable and similar to the expert's answer (Yulita et al., 2019). However, other informants could provide reasons per the expert's answers. Therefore, only DH informants might explain in the context of scientific theory and law. After being able to make inferences, the informant needed to provide an appropriate explanation to support the conclusions that had been presented. Informants gave reasons or arguments through explanations of evidence or examples that support them. Thus, the reason was understandable and similar to the expert's answer (Forawi, 2016).

3.2.6. Self-regulation

Self-regulation skills are the ability to confirm what has been learned, discovered, considered, decided, and concluded (Facione, 2015). The ability to self-regulate has been used by informants when conducting interviews with researchers. The informants also have self-regulatory skills. Informants confirmed the answers described in the questionnaire when the interview was conducted. In the interview results, the informant gave the same answer as the one on the questionnaire. This finding explained that the informant had self-regulatory skills in answering the problems of the basic empirical aspects.

The answers given by the informant when conducting the interview also provided information that the answer followed the expert's answer. The empirical aspect explains why scientists had certainty about the theory put forward. This belief could be trusted until a new theory is found (Yulita et al., 2019). Besides, informants could confirm the answers given when filling out the questionnaire. The answers aligned with the answers the informants wrote on the questionnaire. This case proved that the informant had the skills to self-regulate tentatively.

On the other hand, the informants also had the skills to self-regulate because the informants provided confirmation related to the answers described in the questionnaire when the interview was conducted. In the interview results, the informant gave the same answer as the one on the questionnaire. This finding explained that the informant had the skills to self-regulate in answering problems in scientific theory and legal aspects (Desouza, 2017). When the interview was conducted, the informant could use their self-regulate skill by confirming the answers described in the questionnaire. The interview results were that the informant answered similarly to the answer on the questionnaire. Informants tried to solve the problems given to completion, although some answers did not follow the experts' answers. In this case, the informant used self-regulation skills to solve the creativity problem.

4. Conclusion

The conclusions obtained from this study were that the CT skills possessed by chemistry pre-service teachers: interpretation skills, inference skills, and self-regulation skills. Those skills were still in the low category. Moreover, the participants also lacked in explaining, evaluating, and analyzing the students' abilities. Then, understanding the NoS informants could be categorized in the transitional category. The findings in this study became the input for the department that some students were still unable to analyze NoS aspects in the chemistry context, especially through each stage of CT skills. Also, the researcher suggests that future research improves CT skills in the form of the NoS in chemistry learning, especially for the chemistry pre-service teacher.

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