

Scientific paper

Examining the chemical reasoning of pre-service science teachers using a multiple-choice test based on the essential questions–perspectives framework

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Abstract

The purpose of this study is to examine the chemical reasoning levels of pre-service science teachers. For this purpose, an inventory developed by the researcher in accordance with the Essential Questions-Perspectives Framework (EQ-P) was used as a data collection tool. The inventory consists of thirty-six questions related to three fundamental question types and twelve chemical perspectives. A total of 265 pre-service science teachers from six universities in Turkey participated in the study. A survey model was used in the study. Findings showed that pre-service science teachers performed better on questions related to identification and description. Success was moderate for questions requiring explanation and prediction. Success was lowest for questions requiring transformation and synthesis. When evaluated according to perspectives, high success was observed on questions related to physical properties, structure, composition, and reaction properties. Success was moderate for questions related to particles, interactions, kinetics, and thermodynamics. Success was low for questions related to target molecules, starting materials, addition-removal and process control. The results indicated that the chemical reasoning levels of pre-service science teachers varied significantly depending on the fundamental question types and perspectives. The findings reveal that synthesis and design-oriented thinking should be supported more in chemistry teaching.

Keywords: Science teacher education; Chemical reasoning; Essential Questions–Perspectives Framework; Chemical perspectives.

1. Introduction

Most science and chemistry educators focus on students' understanding of important concepts and ideas.¹ Therefore, a large amount of educational research has been conducted on students' conceptions of chemical phenomena and the majority of this research has focused on uncovering students' alternative conceptions of chemical phenomena.^{2–5} However, the primary goal of a chemistry course is to provide students with knowledge of chemical concepts, models, and theories, as well as to provide students with the skills to analyze data, develop models, and interpret observations. To achieve these goals the types of chemical reasoning we want students to develop need to be clearly defined, and greater emphasis should be placed on chemical reasoning. Chemical reasoning refers to "the development and application of chemical knowledge and

practices with the primary goal of analyzing, synthesizing, and transforming matter for practical purposes".⁶ Identifying students' chemical reasoning skills provides insight into how students understand chemical concepts and how they learn chemistry, consistent with the nature of the chemistry discipline.⁶ Identifying students' chemical reasoning skills allows us to go beyond simply assessing students' content knowledge and to assess their ability to think and argue like scientists.^{7,8}

Many researchers who want to examine how students understand chemical concepts and explain chemical phenomena and reactions have focused their studies on examining students' chemical reasoning.^{9–12} When these researchers' studies are examined, it is understood that they primarily use one of two methods: 1) using frameworks focused on essential questions of the chemistry, 2) using frameworks based on chemical perspectives.^{1,13,14}

However, research examining essential chemistry questions through chemical perspectives is scarce. The Essential Questions–Perspectives (EQ-P) Framework is a new approach and has been reported in only a limited number of studies in the literature.^{15–17} Furthermore, no study has examined pre-service science teachers' chemical reasoning using the EQ-P model. This highlights the need for a comprehensive examination of how pre-service science teachers reason using essential question types and chemical perspectives.

Disciplinary essential questions are defined as open-ended questions that require reasoning, questioning, and detailed thinking.¹⁸ Some researchers have investigated the essential questions of chemistry. For example, according to Hoffmann,¹⁹ there are two essential questions of chemistry: what is matter? (Analysis) and how is matter made? (Synthesis). According to Breslow,²⁰ there are two essential questions of chemistry: how are chemical properties and events explained and predicted? (Investigation and Understanding), and how are new substances and new processes created? (Synthesis and Transformation). In an interview-based study with chemists, Chi et al.¹⁵ identified three essential questions of chemistry: 'What is matter?', 'Why do properties or behaviors of substances arise?', and 'How do we transform and make matter?' Scientific perspectivism is a philosophical approach that emphasizes that events or phenomena can be examined from different perspectives.^{15,21–23} Chemical perspectives, which enable chemical events to be evaluated from different perspectives, play a crucial role in generating alternative and mutually supportive explanations for a chemical event. Examining chemical reasoning by focusing only on essential questions of the discipline of chemistry or relying solely on chemical perspectives has been criticized for its various

limitations. Examining chemical reasoning by focusing only on essential questions of the discipline neglects the examination of reasoning related to how to solve questions about chemical phenomena.^{13,15} Examining chemical reasoning using only perspective-based frameworks can limit or distort students' perspective-taking processes, and thus, chemical reasoning may be assessed as incomplete.²⁴

To extensively evaluate chemical reasoning, a new framework known as the "Essential Questions and Perspectives (EQ-P) Framework" was developed by Chi and fellow¹⁵ researchers, as illustrated in Figure 1.

The EQ-P framework proposes that chemical thinking should be assessed using three essential questions and 12 chemical perspectives. The three essential questions include: Description and Identification (D&I), Explanation and Prediction (E&P), and Transformation and Synthesis (T&S). Each essential question type corresponds to four chemical perspectives. Explanations for the 12 perspectives are provided below.¹⁶

Physical Properties (PhC): Chemical substances can have physical properties that distinguish them from other substances. An individual's ability to identify a chemical substance using physical properties such as odor, hardness, and color is considered relevant to this perspective.

Reaction Properties (RC): Some chemical species have specific reactions. By using these types of reactions, a substance can be identified.

Composition (C): The ratio and distribution of species constituting matter influence its properties. The composition perspective is based on the fact that the ratio or distribution of species (such as molecules or ions) that constitute matter influence its properties. The structural state or interactions of the species that constitute matter are not relevant to this perspective.

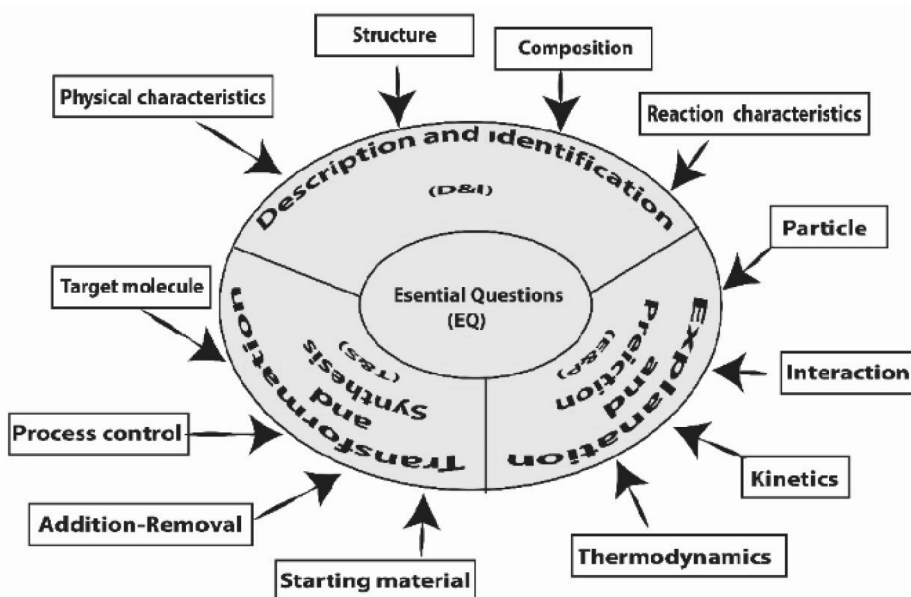


Figure 1. Framework of Essential Questions and Perspectives¹⁵

Structure (S): The structure perspective relates to the fact that each chemical substance has a unique chemical structure. A person can identify a chemical substance by its unique structure.

Particle (P): Explaining the properties of a chemical substance or a chemical process in terms of the particles that make up matter is related to this perspective. Explanations that consider submicroscopic species such as electrons, protons, neutrons, atoms, and molecules fall within this perspective.

Interaction (I): Explanations that take into account the interactions of submicroscopic species such as atoms, ions, and molecules fall within the scope of this perspective.

Thermodynamic (T): The spontaneity of a chemical event depends on the energy changes associated with the system and its surroundings. The use of thermodynamic factors such as heat changes, enthalpy, and entropy to explain a chemical process is related to the thermodynamic perspective.

Kinetics (K): Factors such as reaction rate and activation energy play important roles in the occurrence of a chemical event or reaction. The use of kinetic factors in explaining a chemical event or reaction is related to the kinetic perspective.

Target Material (TM): Knowing the chemical structure of the product to be synthesized (target material) is crucial in the production of a material. A detailed understanding of the chemical structure of the target material is crucial to determine the chemicals required to synthesize that target product and also for determining the procedure to be followed.

Starting Material (SM): To synthesize a substance using chemical methods, it is essential to identify suitable starting chemicals. Knowing the structures and properties of the chemicals involved in the reaction is crucial to synthesize the desired product and to adjust the reaction conditions.

Addition–Removal (AR): Synthesis of a desired product may require the addition or removal of certain groups during a chemical reaction. The addition of certain chemicals to protect a specific functional part of a molecule during the reaction process is also relevant to this perspective.

Process Control (PC): The transformation of one substance into another occurs through chemical reactions. During chemical reactions, many factors (e.g., temperature, pressure, and heat transfer) affect the rate of reaction and, consequently, product yield. The process control perspective is concerned with the intentional control of all factors affecting a chemical reaction (thermodynamic and kinetic factors) and the implementation of necessary interventions.

EQ-P addresses three fundamental questions in chemistry. The fundamental questions are: a) What is matter? b) Why do the properties and behaviors of matter arise? c) How do we transform or synthesize substances?

According to EQ-P, each fundamental question relates to four different perspectives (12 perspectives in total). For example, the question "Why do the properties and behaviors of matter arise?" can be addressed using particle, interaction, thermodynamic, or kinetic perspectives. Models such as **Bloom's Taxonomy** and SOLO are useful for explaining learning processes. However, such models are inadequate for examining chemical thinking in depth. EQ-P, on the other hand, offers the opportunity to simultaneously evaluate chemistry questions and chemical reasoning methods. This allows us to understand not only whether students are recalling and applying information, but also from which chemical perspective they are thinking. Previous research has shown that chemistry teaching often focuses on the transmission of knowledge. However, the questions chemists ask and the perspectives from which they answer them are often overlooked. EQ-P fills this gap, allowing students to track, categorize, and discuss different aspects of chemical thinking through their own responses.

Research to date has shown that the EQ-P is an effective tool for making students' chemical thinking visible. For example, it has been used in content analysis of textbooks and revealed how different chemical perspectives are represented.¹⁷ The EQ-P has also been applied to examine how high school students use chemical perspectives.¹⁶ The multiple-choice test developed in this study is test designed to examine the chemical reasoning of university-level pre-service teachers. In this respect, the study is the first to examine the chemical reasoning of university students using multiple-choice questions specifically designed according to the EQ-P framework.

The purpose of this study is to examine pre-service science teachers' chemical reasoning processes through multiple-choice questions developed according to the EQ-P (Essential Questions – Perspectives) framework and to reveal pre-service teachers' success levels in different chemical perspectives. The main research question of this study is, "What is the distribution of pre-service science teachers' chemical reasoning success across the EQ-P question types and perspectives" In this context, the following sub-research questions were addressed:

- What is the distribution of pre-service science teachers' success levels according to the EQ-P essential question types (description and definition [D&I], explanation and prediction [E&P], transformation and synthesis [T&S])?
- What is the distribution of science teacher candidates' achievement levels based on EQ-P perspectives (e.g., physical properties, particles, kinetics, etc.)?
- Is there a statistically significant difference in pre-service science teachers' achievement scores across the three EQ-P essential question types (Description & Identification, Explanation & Prediction, Transformation & Synthesis)?

- Is there a statistically significant difference in pre-service science teachers' achievement scores across the twelve EQ-P chemical perspectives?

2. Method

2.1. Research design

This study employed the descriptive survey model, one of the quantitative research designs, to examine pre-service science teachers' chemical reasoning within the EQ-P framework. The descriptive survey model is an approach based on the analysis of data obtained from a large sample group and aims to describe the current state.²⁵

2.2. Study context

The study was carried out in the context of the General Chemistry and Foundations of Science Education courses taken by pre-service science teachers in Turkish universities. These courses typically follow a conceptual understanding and inquiry-oriented instructional approach, which encourages students to interpret chemical phenomena using models, representations, and problem-solving strategies. This instructional environment aligns with the purpose of the EQ-P framework and supports the validity of administering the EQ-P Chemical Reasoning Inventory to this group.

2.3. Participants

The study was conducted with the participation of 265 prospective teachers enrolled in the Science Education Department of the Faculty of Education, years 1–4, at Firat University, Van Yüzüncü Yıl University, Dicle University, Muş Alparslan University, İnönü University, and Ağrı İbrahim Çeçen University, all located in Turkey. Participants ranged in age from 18 to 24. Fifty-three percent of the participants were female, and the remainder were male. The distribution of students by grade level was as follows: 10 percent were first-year students, 17 percent were second-year students, 37 percent were third-year students, and 36 percent were fourth-year students. Because there has been a significant decrease in the number of students applying for science education programs across Turkey over the past two years, the number of first- and second-year students is lower than that of other grades. The distribution of participants by university was as follows: 48 students from Firat University, 41 from Van Yüzüncü Yıl University, 45 from Dicle University, 40 from Muş Alparslan University, 49 from İnönü University, and 42 from Ağrı İbrahim Çeçen University. This study was approved by the Ethics Committee of Firat University (Approval No. 38704). Participation was voluntary, and informed consent was obtained from all participants.

2.4. Instrument: EQ-P framework chemical reasoning inventory

In this study, the “The EQ-P Chemical Reasoning Inventory” developed by the researcher was used as the data collection tool. The inventory consists of 36 multiple-choice questions. The questions are related to the three essential question categories and twelve chemical perspectives in the EQ-P framework. Each question is aligned with only one perspective. The questions in the inventory are provided in the Appendix. However, a sample question for each essential question category is presented below: “Which of the following pairs of metal powders can be separated using a magnet?” (This question relates to D&I-PhC). “Which of the following options correctly gives the rate expression for the one-step reaction shown as $aX(g) + bY(g) \rightarrow 2Z(g)$?” (This question relates to E&P-K). “Alcohols can be obtained by adding water to alkenes. “Which alkene can be used to synthesize isopropyl alcohol using this method?” (This question relates to T&S-SM).

Content validity: The questions in the inventory were initially reviewed by three chemistry professors. They were assessed for their conformity with the EQ-P framework, content validity, and language clarity. As a result of the analysis, it was determined that the item-level Content Validity Ratios (CVR) ranged from 0.62 to 0.89. In addition, the scale-level Content Validity Index (S-CVI/Ave.) was found to be 0.89.

Pilot Study: The initial 45-item form was administered to a sample of 62 pre-service science teachers. Item difficulty (p) and item discrimination (r_{pb}) values were calculated. Items with difficulty indices between 0.20 and 0.80 and discrimination coefficients of $r_{pb} \geq 0.20$ were retained. Nine items that did not meet these criteria were removed.

Reliability Analysis: The KR-20 coefficient for the first version of the inventory consisting of 45 questions was 0.71. However, the KR-20 coefficient for the final version consisting of 36 questions was calculated to be 0.82.

2.5. Data analysis

Data obtained from the inventory were analyzed to determine pre-service teachers' achievement levels across essential question types (D&I, E&P, T&S) and chemistry perspectives. Each correct answer was scored as 1 point, whereas incorrect or blank responses were scored as 0. Thus, total scores ranged from 0 to 36. Since each essential question category contains 12 items, category-based scores range from 0 to 12. Each perspective contains 3 items, resulting in perspective-based scores ranging from 0 to 3.

3. Results and discussion

The following steps were performed to determine the distribution of pre-service science teachers' success

across EQ-P essential question types (D&I, E&P, T&S): First, the obtained scores were converted to success percentage. For this purpose, a student's success rate for the essential question type was calculated using the formula "(Number of Correct Answers/12)×100," and their success rate for the perspective was calculated using the formula "(Number of Correct Answers/3)×100." The mean for all students was calculated from these success percentages. The distribution of pre-service science teachers' success rates across EQ-P essential question types (D&I, E&P, T&S) is presented in Table 1.

Table 1. Distribution of teacher candidates' success according to EQ-P essential question types (D&I, E&P, T&S)

Essential Question	Number of Items	Number of Students	Average Correct Answers	Average Success (%)
D&I	12	265	8,24	68,65
E&P	12	265	6,31	52,58
T&S	12	265	4,01	33,40

The highest success rate in the D&I category indicates that pre-service teachers were more comfortable with solving questions requiring the ability to describe and identify matter by utilizing its composition, structure, physical properties, or reaction properties than other questions. This indicates that pre-service teachers' chemical reasoning skills related to these abilities were at a moderate-to-high level. The relatively high performance of prospective teachers in the D&I category in this study is noteworthy. This may be related to the content structure of chemistry education in Turkey. Curricula and textbooks largely focus on identifying, classifying, and distinguishing the properties of matter. Throughout their high school education, students are frequently exposed to exercises specifically focused on identifying physical and chemical properties and distinguishing substances. Therefore, it is not surprising that the majority of pre-service teachers had no difficulty with questions related to D&I perspectives. The 52.58% success rate on questions related to the E&P category indicates that students' ability to explain chemical phenomena by incorporating particles, interactions between particles, and kinetic or thermodynamic factors is at a moderate level. This rate indicates that students struggled with questions related to the E&P category. Questions in the E&P category are related to the ability to establish cause-and-effect relationships. It is a well-known fact that students struggle to grasp the cause-effect relationships of chemical phenomena. For example, while interpretations based on interactions or energy changes are common, explanations in broader contexts can be limited. This resulted in moderate performance in the E&P category, lower than D&I but higher than T&S. The lowest success rate was

found in the T&S category. This suggests that students' success rates on questions related to chemical transformation, synthesis, and process control—and therefore their chemical reasoning—were low. The low performance in the T&S category indicates that pre-service teachers had difficulty with questions involving chemical transformation and synthesis. Synthesis, design, and process control tasks are typically emphasized in advanced organic or industrial chemistry courses, and these topics are covered more superficially in science education programs. As a result, students may have limited familiarity with questions that require selecting starting materials, designing synthetic routes, or controlling reaction processes. This may be partly due to the way synthesis and design-type tasks are presented in current curricula and course materials. It may also be due to students' inadequate exposure to tasks requiring higher-order thinking or assessment methods that include such questions. Although curriculum-related factors may contribute to this pattern, other instructional and experiential factors may also play a role. Similar findings have been reported in the international literature. For example, Chi et al.'s¹⁷ review of Chinese high school chemistry textbooks reported a significant underrepresentation of the T&S category. However, it should be noted that this comparison is not directly in the same context. While the Chinese study focused on high school textbooks, this research examines the achievement of university-level pre-service teachers. Therefore, while the findings suggest a similar trend, this trend differs in terms of educational level and objectives.

The distribution of pre-service science teachers' success across EQ-P perspectives is presented in Table 2.

Table 2. Distribution of prospective teachers' success according to perspectives

Perspective	Number of Items	Number of Students	Average Correct Average	Answers Success (%)
PhC	3	265	2,08	69,50
S	3	265	2,02	67,40
C	3	265	2,01	67,00
RC	3	265	2,00	66,70
P	3	265	1,57	52,30
I	3	265	1,55	51,50
K	3	265	1,53	50,90
T	3	265	1,49	49,70
TM	3	265	1,01	33,60
SM	3	265	0,99	33,00
AR	3	265	0,96	32,00
PC	3	265	0,95	31,70

The results in Table 2 indicate that prospective teachers were more successful with the Structure (S) perspective. This may be related to the fact that chemistry education in schools generally focuses on the structure of

substances and their representations. Relatively high success was also seen with the Physical Properties (PhC) perspective. This is consistent with the emphasis placed on physical and chemical properties in curricula and textbooks. In contrast, success rates were lower for the Thermodynamics (T) and Kinetics (K) perspectives. Success in questions related to these perspectives requires high-level reasoning on topics such as energy changes, reaction rates, and dynamic processes. For this reason, these topics are generally perceived as difficult by students. Pre-service teachers performed poorly on questions related to perspectives under the T&S category (e.g., SM, AR, and PC). This result is not surprising, as tasks related to T&S perspectives are less frequently included in teacher preparation programs. Pre-service teachers appear to have relatively less difficulty with tasks related to structure and properties. However, they struggle with tasks requiring abstract reasoning or design thinking. The highest success rates are seen in questions related to PhC (69.50%), S (67.40%), C (67.00%), and RC (66.70%) perspectives. This result suggests that pre-service teachers are more capable of identifying substances using their physical properties, structural characteristics, composition, or distinctive reaction properties. Success rates are at a moderate level in the P (52.30%), I (51.50%), K (50.90%), and T (49.70%) perspectives. This indicates that the candidates are partially successful in explaining chemical phenomena at the particle level, using interactions between particles, or using kinetic and thermodynamic principles. The pre-service teachers have a moderate level of reasoning skills in chemistry topics related to these perspectives. The lowest success rates are observed in the TM (33.60%), SM (33.00%), AR (32.00%), and PC (31.70%) perspectives. This suggests that prospective teachers are particularly challenged with synthetic/design reasoning skills (e.g., selecting the appropriate starting material, accessing the target molecule, adding/removing groups, optimizing the process for yield or purity). Pre-service teachers' chemical reasoning skills related to these perspectives are low.

Statistical analyses were conducted to determine whether the differences in the success levels of pre-service teachers in the essential question types (D&I, E&P, T&S) were statistically significant. First, the Shapiro–Wilk test was applied to test the normality of the distributions. The results of the Shapiro–Wilk test showed that the distributions for all three essential question types were not normal ($p < .001$). Therefore, the non-parametric Friedman test was applied. The Friedman test results showed that the success levels of pre-service teachers differed significantly according to the essential question types ($\chi^2(2) = 342.114$, $p < 0.001$). Considering the mean ranks, the order of success was D&I (2.76) > E&P (2.03) > T&S (1.21). The Wilcoxon Signed-Rank Test, conducted to determine which categories exhibited significant differences, found a statistically significant difference in all pairs among the three categories (D&I–E&P, D&I–T&S, E&P–T&S) ($p < 0.001$).

Consequently, pre-service science teachers' chemical reasoning showed significant differences according to the essential question types. Their reasoning on items aligned with the perspectives under the D&I category (PhC, S, C, RC) was found to be at a high level, their reasoning on items aligned with the perspectives under the E&P category (P, I, T, K) was at a moderate level, and their reasoning on items aligned with the perspectives under the T&S category (TM, SM, AR, PC) was found to be at a low level.

Similar statistical analyses were conducted to determine whether the differences in achievement levels of prospective teachers across chemical perspectives were statistically significant. The Shapiro–Wilk test results indicated that the distributions for all 12 chemical perspectives were not normal ($p < 0.001$). The Friedman test results indicated that the achievement levels of prospective science teachers differed significantly across perspectives ($\chi^2(11) = 682.635$, $p < 0.001$). Considering the mean ranks, the highest achievement was observed in the S (8.48), RC (8.47), C (8.28), and PhC (8.15) perspectives. The lowest success was observed in the TM (4.48), AR (4.58), PC (4.57), and SM (4.62) perspectives. Moderate success was achieved in the P (6.71), I (6.78), T (6.63), and K (6.26) perspectives, which are related to particle-level and process-based explanations. As a result, pre-service science teachers' chemical reasoning skills differed significantly across the perspectives. Their reasoning skills on items aligned with the perspectives under the D&I category (PhC, S, C, RC) were found to be high, their reasoning levels on items aligned with the perspectives under the E&P category (P, I, T, K) were moderate, and their reasoning skills on items aligned with the perspectives under the T&S category (TM, SM, AR, PC) were found to be low. The T&S category (Transformation and Synthesis) relates to the process of organizing chemical reactions to produce or synthesize new chemicals. This process involves knowing the structure and properties of the chemical to be synthesized, identifying appropriate starting reagents, and controlling the process in various ways. This type of reasoning requires higher-order cognitive skills. In the current study, the low level of pre-service teachers' reasoning skills related to perspectives in the T&S category (TM, SM, AR, PC) may indicate that their higher-order cognitive skills are not yet sufficiently developed. One possible reason for this is the inadequate coverage of topics related to the T&S category in curricula or textbooks. Indeed, in their study examining Chinese high school chemistry textbooks within the EQ-P framework, Chi and colleagues¹⁷ found that only 12% of the content was related to the T&S category. Therefore, the current study's findings regarding the T&S category are consistent with Chi and colleagues' findings and suggest that this deficiency in course materials may be reflected in pre-service teachers' limited reasoning skills related to chemical synthesis.

In a study on students' difficulties in using chemical representations, it was found that students had difficulty

understanding peak and trough heights, step numbers, stoichiometry, and mechanism relationships in visual-quantitative representations such as reaction coordinate diagrams.²⁶ Similarly, in this study, pre-service teachers were found to perform worse in E&P questions, particularly those focusing on the kinetic perspective, than in other categories. Talanquer²⁶ stated that students often reason erroneously about molecular formulas and Lewis structures, that most students struggle with tasks requiring detailed explanations, particularly at the particle, atom, and electron levels, and that their success in these tasks is only moderate. The current study, similar to the results of Talanquer's study found that students performed moderately on questions from the particle (P) and interaction (I) perspectives. Talanquer also reported similar difficulties understanding energy diagrams. The current study also found that students did not perform well on questions from the Thermodynamics (T) perspective, with a success rate of 49.7%. Barker and Millar¹¹ examined students' explanations of chemical reactions. Their study found that students struggled to explain the mechanisms of chemical reactions at the molecular level. Similar results were obtained in the current study. While the performance of pre-service science teachers in questions requiring the ability to identify and distinguish the properties of matter (D&I category) is at a good level, their performance in questions related to the E&P and especially the T&S category is low. This result suggests that pre-service teachers perform well at the macro level but struggle with questions requiring explanation at the micro level. Various studies have also noted that non-observable properties such as molecular geometry, bond structure, and intermolecular interactions are difficult to understand.^{27,28} The difficulties inherent in the particle and interaction perspectives in this study are consistent with these findings.

These results have several important implications for the teacher education process. The difficulties observed in the E&P and especially T&S categories indicate that pre-service teachers need more practice on questions requiring explanation, prediction, synthesis, and design. Regular practice of particle-level explanations, reaction mechanisms, and synthesis-type problems can improve these skills. Incorporating such activities into teacher education courses can better prepare pre-service teachers to develop students' chemical reasoning. One of the primary goals of chemistry education is to develop students' chemical reasoning skills. This skill helps students achieve greater academic success. It also raises awareness of issues of public concern.²⁹ Numerous studies show that individuals with strong chemical reasoning skills also have higher logical, critical, and creative thinking skills.^{30–32} Determining students' chemical reasoning levels helps teachers plan instruction appropriate to their thinking. In this regard, recent studies have shown that the EQ-P framework is a useful tool for assessing students' chemical reasoning.

4. Conclusions

In this research, the chemical reasoning of prospective science teachers was analyzed using the EQ-P (Essential Questions–Perspectives) framework, contributing significantly to addressing a gap in the existing literature. The findings of the study indicate that there are significant differences in the essential question types and perspectives used in pre-service science teachers' chemical reasoning. As a result of the research, it was determined that pre-service science teachers were generally successful in questions related to D&I category perspectives. However, they demonstrated moderate proficiency in questions related to E&P perspectives. The study findings revealed that pre-service science teachers struggled with questions related to T&S perspectives. This suggests that pre-service science teachers perform well on tasks involving description and identification. They demonstrated moderate success in tasks involving explanation and prediction. However, the study findings indicate that pre-service science teachers generally struggle with tasks requiring skills related to chemical reaction regulation and process control.

In terms of perspectives, pre-service science teachers demonstrated good proficiency in physical properties (PhC), structure (S), composition (C), and reaction properties (RC). However, they exhibited lower success rates in the target molecule (TM), starting material (SM), addition–removal (AR), and process control (PC) perspectives. The T&S category, in which pre-service science teachers demonstrated limited success, encompasses perspectives related to higher-order cognitive abilities. The finding that pre-service teachers experienced difficulties in these areas further underscores the importance of developing higher-order thinking skills in chemistry education.

The current research has demonstrated that the EQ-P framework is a powerful tool for comprehensively assessing pre-service teachers' chemical reasoning. A comprehensive analysis using the EQ-P framework, both in terms of fundamental questions and perspectives, allowed for a clear identification of pre-service teachers' strengths and weaknesses. The findings provide important and valuable information for researchers and educators in the field of chemistry education. The results of the study will guide program and curriculum developers. The research results once again demonstrate the need to strengthen certain aspects of pre-service science teachers' education. Pre-service teachers do not experience difficulties in identifying matter and determining its properties. However, they have difficulty with tasks related to chemical synthesis and transformation. Therefore, it would be beneficial to include more emphasis on synthesis and design processes in teacher education programs. Furthermore, this study provides an example of the use of multiple-choice tests based on the EQ-P framework at the university level. Future research can be conducted with different samples. Studies conducted at different levels of education will also allow for comparison of findings.

4. 1. Limitations

This research has some limitations. The study was conducted with the participation of prospective science teachers from six universities in Turkey. Therefore, the generalizability of the research results is limited. The study used a multiple-choice test specifically designed for the EQ-P framework. This tool offers significant contributions to the study of chemical reasoning. However, the results of this study may not be as comprehensive as those obtained from a study using open-ended questions specifically designed for the EQ-P framework.

4. 2. Implications

The findings of this study contribute to useful inferences for chemistry education. Increasing emphasis on activities that support higher-order reasoning and thinking in the curricula of teacher education institutions could further contribute to the cognitive development of prospective teachers. These activities, designed for prospective chemistry or science teachers, could focus more on chemical synthesis tasks, reaction setup tasks, or the control of reaction conditions and environments. Chemistry textbooks and teaching materials could be designed to broaden the scope of the concepts of chemical synthesis, the control of chemical reaction processes, and chemical transformations. In classroom instruction, students could be given more opportunities to explain chemical phenomena and macroscopic observations at the particle level. These implications aim to contribute to the training of chemistry/science teachers with more advanced chemical reasoning skills.

4. 3. Future Research

Because the EQ-P framework is a new model, further studies with different sample groups are needed. Therefore, future studies could examine the chemical reasoning skills of students at different educational levels using the EQ-P framework. In the current study, multiple-choice questions were used as measurement tools. In the future, research can be conducted using open-ended questions specifically prepared for the EQ-P framework in different chemistry topics to examine students' chemical reasoning in more depth. Future studies can also be conducted to examine the effects of using different educational methods or techniques on students' chemical reasoning using the EQ-P framework. In addition, comparative studies across countries using the EQ-P framework could be conducted. This would allow for a more detailed examination of the relationships between curriculum differences and chemical reasoning.

Conflicts of Interest

There are no conflicts of interest to declare.

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Povzetek

Namen te raziskave je preučiti raven kemijskega razumevanja bodočih učiteljev naravoslovja. V ta namen je bil kot orodje za zbiranje podatkov uporabljen inventar, ki ga je razvil raziskovalec v skladu z okvirom bistvenih vprašanj in perspektiv (EQ-P). Inventar obsega šestintrideset vprašanj, povezanih s tremi osnovnimi vrstami vprašanj in dvanajstimi kemijskimi perspektivami. V študiji je sodelovalo skupno 265 bodočih učiteljev naravoslovja iz šestih turških univerz. V študiji je bil uporabljen model ankete. Rezultati so pokazali, da so bodoči učitelji naravoslovja dosegli boljše rezultate pri vprašanjih, povezanih z identifikacijo in opisom. Uspešnost je bila zmerna pri vprašanjih, ki so zahtevali razlago in napovedovanje. Najnižja uspešnost je bila pri vprašanjih, ki so zahtevali transformacijo in sintezo. Pri ocenjevanju glede na perspektive je bila visoka uspešnost opazna pri vprašanjih, povezanih s fizikalnimi lastnostmi, strukturo, sestavo in reakcijskimi lastnostmi. Uspešnost je bila zmerna pri vprašanjih, povezanih s delci, interakcijami, kinetiko in termodinamiko. Uspešnost je bila nizka pri vprašanjih, povezanih s ciljnimi molekulami, izhodnimi snovmi, dodajanjem in odstranjevanjem ter nadzorom procesov. Rezultati so pokazali, da se raven kemijskega razmišljanja bodočih učiteljev naravoslovja znatno razlikuje glede na osnovne vrste vprašanj in perspektive. Rezultati raziskave kažejo, da je treba v poučevanju kemije bolj razvijati sintezo in oblikovalsko usmerjeno razmišljanje.



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