

Received	: 8 June 2026
Revised	: 21 June 2026
Accepted	: 26 June 2026
Published	: 30 June 2026

## Nature of Science and Technology-Based Didactical Design on Structure and Physicochemical Property Relationships of Ionic Liquids for Pre-Service Teachers

Devita Marlina Venessa<sup>1,\*</sup>, Ariyatun<sup>1</sup>, Vida Zenitha Sudariasri<sup>1</sup>, Rini Fath Marsya<sup>2</sup>

<sup>1</sup>Department of Chemistry Education, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Negeri Jakarta, Jl. Rawamangun Muka, Rawamangun sub-district, Pulo Gadung district, East Jakarta City, Special Region of Jakarta, 13320

<sup>2</sup>Department of Chemistry, Universitas Teknologi Nusantara, Pangkalan Dua Regional Government Highway No. 66, Kedung Halang, North Bogor District, Bogor City, West Java, 16158

Email: [devita.marlina@unj.ac.id](mailto:devita.marlina@unj.ac.id)\*

### Abstract

Understanding the Nature of Science and Technology (NOST), as well as strengthening the conceptual mastery of pre-service chemistry teachers by connecting scientific concepts with cutting-edge technological contexts, particularly ionic liquids, remains a challenge in chemistry education. This study aims to design a didactic framework that focuses on the relationship between the structure and physicochemical properties of ionic liquids to develop NOST perspectives and improve conceptual understanding among pre-service chemistry teachers. A descriptive qualitative approach was used with the Didactical Design Research (DDR) model, which includes literature analysis, identification of preconceptions, and mapping of NOST indicators as the foundation for constructing didactic situations. The resulting instructional design is based on seven aspects of NOST to develop relevant didactic situations. Data on NOST perspectives, the seven NOST aspects, and learning barriers were used to design didactic situations, predict responses from pre-service chemistry teachers, and anticipate educators' actions (ADP). Validation results indicate that this design is feasible to implement, although some improvements are needed regarding language clarity and the appropriateness of learning activities. The implementation of this didactic design has the potential to enhance concept mastery among pre-service chemistry teachers. Pre-test and post-test results show a significant improvement across all sections of the test, with an average increase of 34.3%. These findings demonstrate that a didactic design which considers students' learning obstacles and the seven aspects of NOST is effective in helping pre-service chemistry teachers actively and systematically build conceptual understanding.

**Keywords:** Didactic design, NOST, ionic liquid, pre-service chemistry teachers, physicochemical properties.

## Introduction

Strengthening understanding of the Nature of Science and Technology (NOST) remains a challenge in science education, particularly in teacher education (Cullinane & Erduran, 2023; Dorsah, 2020). This challenge becomes even more complex when scientific knowledge must be integrated with the rapid development of technology (Cullinane & Erduran, 2023; Ha et al., 2023). Within the framework of science and technology literacy, understanding the relationship between science and technology is crucial not only for building conceptual knowledge but also for shaping individuals' ability to explain phenomena, make evidence-based decisions, and respond to social issues influenced by technological advances (Liman & Kaptan, 2024; Wong et al., 2011).

Several studies show that pre-service teachers' understanding of the nature of science and technology remains underdeveloped (García-Carmona, 2022; Venessa et al., 2019; Zhang et al., 2022). This understanding is often fragmentary, in which science is viewed as a collection of facts or laws, while technology is seen as merely a product or tool (Ba et al., 2025; Cullinane & Erduran, 2023). This view is not in line with the contemporary view that places science and technology in a reciprocal relationship, where technological developments can encourage scientific inquiry while also depending on the construction of scientific knowledge (Dorsah, 2020; Svendsen, 2021; Tala, 2013; Venessa et al., 2019). Limitations in this epistemic understanding can hinder prospective teachers' ability to design learning that is not only oriented towards mastery of concepts but also towards the development of scientific thinking (López-Banet & Martínez-Carmona, 2021; Paricio et al., 2022).

The findings of preliminary studies further confirm this issue, whereby prospective chemistry teachers' views on the Nature of Science and Technology (NOST) tend to fall into the Has Merit category (Nurhadi et al., 2020; Venessa et al., 2019). These views indicate that prospective teachers' understanding is not yet fully aligned with scientific views. Science and technology are often perceived as separate entities, leading to their suboptimal integration into learning practices (Mafugu et al., 2022). This condition underscores the urgent need to develop learning designs that explicitly integrate NOST characteristics while overcoming the epistemological barriers pre-service teachers encounter.

One context that could bridge this integration is ionic liquids. This context can illustrate the close relationship between the development of chemical concepts and modern technological innovations (Hernani et al., 2016; Rauber et al., 2019; Riley & Dutta, 2024). As materials widely used in green chemistry, catalysis, separation processes, and biocatalysis, ionic liquids offer a valuable context for demonstrating how scientific knowledge is constructed, tested, and applied in technological engineering (Badgujar et al., 2022; Sheldon, 2021). However, this context is still rarely integrated into chemistry education, so its potential to support the development of NOST understanding has not been fully utilised (Hernani et al., 2016; Nurhadi et al., 2020; Riley & Dutta, 2024).

Previous research shows that pre-service chemistry teachers have difficulty connecting chemistry concepts to the context of ionic liquid technology, especially at the submicroscopic and symbolic levels (Kapici, 2023; Venessa et al., 2020). These difficulties not only reflect limitations in conceptual mastery but also indicate the absence of connections among empirical evidence, scientific representations, and theoretical explanations (Kapici, 2023). In other words, the learning barriers that arise are epistemological in nature and require a systematically designed learning approach (Guerra et al., 2019; Yeşiloğlu & Köseoğlu, 2020).

Research on the understanding of the Nature of Science and Technology (NOST) among pre-service chemistry teachers has been conducted (Cullinane & Erduran, 2023; García-Carmona, 2022). Similarly, several researchers have explored ionic liquids as a context for modern chemistry education. However, systematic reviews of these studies have not explicitly integrated NOST aspects into didactic design research, particularly those focusing on the relationship between structure and the physicochemical properties of ionic liquids. Existing research generally focuses on measuring NOST perspectives without translating them into instructional design (Venessa et al., 2019; Zhang et al., 2022) or developing teaching materials based on the seven NOST aspects as a systematic design framework. This gap indicates the

absence of an instructional design approach capable of addressing epistemological barriers and enhancing understanding of NOST in the context of modern chemistry.

Didactical Design Research (DDR) provides a theoretically grounded framework to address this gap. Developed by Suryadi (2019), DDR consists of three iterative stages: (1) analysis of prospective chemistry teachers, which involves constructing a Hypothetical Didactic Design (HDD) based on identified learning obstacles and anticipated student responses; (2) metapedadidactic analysis conducted during implementation; and (3) retrospective analysis that connects the hypothetical design with empirical findings to produce a refined Empirical Didactic Design (Erika et al., 2022; Fauzi & Suryadi, 2020). Unlike conventional instructional design models, DDR explicitly prioritizes learning obstacles, epistemological, and didactic as the primary basis for design decisions (Suryadi, 2019). Therefore, DDR is particularly well suited to integrating Nature of Science Teaching (NOST) principles into chemistry education, where epistemological barriers have been well documented (Kapici, 2023; Venessa et al., 2019).

Although studies on pre-service teachers' views of NOST and their understanding of the structure and physicochemical properties of ionic liquids have been conducted, studies that explicitly integrate these two in a didactic design remain very limited. The limitations of this research indicate the need for an approach that focuses not only on what students learn but also on how that knowledge is constructed through scientific practice (Irwanto, 2023; Suryati et al., 2024). Based on these considerations, this study aims to develop a didactic design that aligns with NOST principles and addresses the learning barriers faced by pre-service chemistry teachers, focusing on the relationship between the structure and physicochemical properties of ionic liquids. This design is expected not only to support concept mastery but also to facilitate the development of epistemic understanding of how scientific knowledge is constructed and used to explain phenomena. Thus, this study seeks to strengthen a conceptual, contextual, and science-literacy-oriented chemistry learning framework for pre-service teachers.

## Method

The method used in this study is descriptive qualitative research using the didactical design research (DDR) model. This model is used to produce a learning design that incorporates NOST and aligns with the analysis of students' learning obstacles in the context of the relationship between structure and the physicochemical properties of ionic liquids. The subjects of this study were 23 sixth-semester undergraduate students from the Chemistry Education Study Program at a university in South Sumatra, Indonesia, who had previously completed courses in Inorganic Chemistry and Organic Chemistry. The preliminary data, including initial VNST profiles and learning obstacles of pre-service chemistry teachers related to ionic liquid content, were obtained from prior published studies (Venessa et al., 2019, 2020) and served as the basis for designing the hypothetical didactical framework in the present study. Data in this study were collected using the View of Nature of Science and Technology (VNOST) questionnaire adapted from Aikenhead et al. (1998) and modified by Tairab (2001), post-test essay items guided by ionic liquid technology discourse, and a didactic design validation sheet assessed by six expert validators comprising chemistry and chemistry education lectures. DDR consists of three stages, namely (1) the didactic situation stage before learning, (2) the didactic situation stage during learning or metapedagogical analysis, and (3) the didactic situation stage after learning (Erika et al., 2022; Fauzi & Suryadi, 2020).

In this article, the research results focus on the didactic design of the relationship between the structure and physicochemical properties of ionic liquids, which have been tested to a limited extent. The results of the NOST analysis and the preconceptions of pre-service chemistry teachers are not discussed in this article and are used only as a basis for designing a hypothetical didactic framework for the relationship between structure and the physicochemical properties of ionic liquids. The results of observation and descriptive analysis, along with students' VNST ability and final concept mastery during and after implementation, serve as the basis for revising the didactic design hypothesis regarding the relationship between the structure and physicochemical properties of ionic liquids. The research procedure, based on this flow, is carried out in the following stages, and the research flow diagram is shown in Figure 1.

1. Learning objectives were analysed based on the results of an analysis of the chemistry education curriculum, textbooks, and articles related to the concept of the structure-property relationship of ionic liquids within the framework of Nature of Science and Technology (NOST).
2. VNOST analysis and the learning outcomes of pre-service chemistry teachers are analysed to design didactic situations that are in line with the seven aspects of NOST and the needs of students, namely the characteristics of science, the objectives of science, scientific research, scientific knowledge, the characteristics of technology, scientific theory, and the relationship between science and technology. The didactic situations were developed by integrating the context of ionic fluid technology with the basis of didactic relationships (DR) and pedagogical relationships (PR). Learning activities, predictions of student responses, and educator anticipations were also part of the didactic situations developed to overcome learning barriers and develop teachers' understanding of VNOST
3. Didactic Design Hypothesis (DDH) was validated by involving six expert validators (chemistry/chemistry education lecturers) to assess the suitability of learning objectives with the learning situation, the relevance of the NOST core, consistency with predicted student responses, and the completeness of educator anticipation. Suggestions for improvement from the validators were incorporated to revise and refine the design, resulting in a valid hypothetical learning design ready for testing in the next implementation stage.
4. The revised didactic design hypothesis based on the validation results was implemented into learning activities. Learning activities were extensively observed in the interactions between educators and prospective chemistry teachers. The observations focused on the learning situations, student responses, and educators' anticipation of student responses.
5. The results of the VNOST questionnaire and final concept mastery were analysed to determine the potential of the didactic design in developing VNOST and concept mastery among prospective chemistry teachers.
6. The didactic design hypothesis was revised based on an overall analysis of the didactic situation, student responses, educator anticipation, and the results of the VNOST questionnaire and final test.

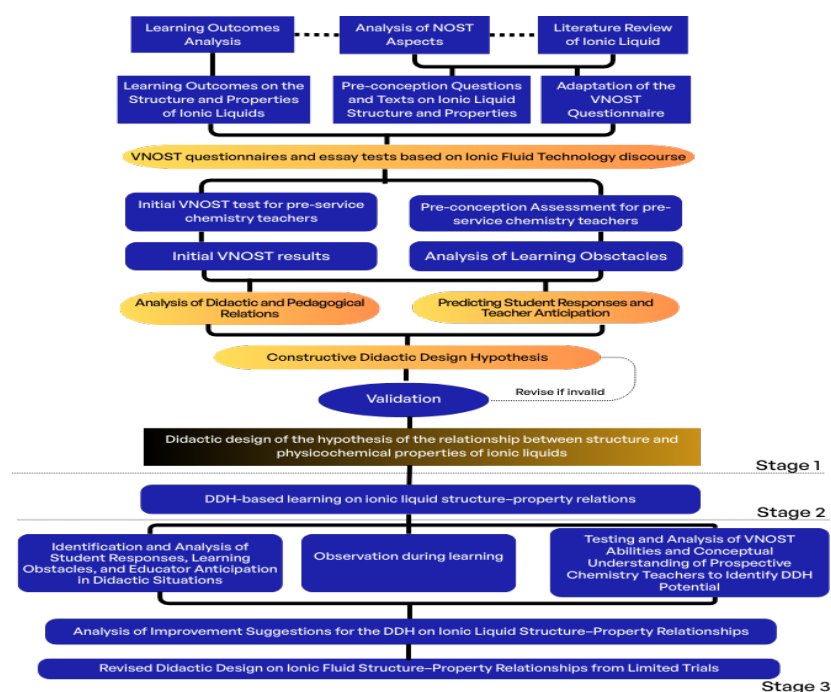


Figure 1. Research Flowchart

## Results and Discussion

The didactic design for the relationship between the structure and the physicochemical properties of ions was developed based on seven aspects of NOST: scientific characteristics, scientific objectives, scientific research, scientific knowledge, technological characteristics, scientific theory, and the relationship between science and technology. Learning outcomes and learning objectives were analysed through a literature review of ionic liquid teaching materials developed by prior researchers, as well as other relevant sources on ionic liquids, and were integrated into the learning outcomes of high school chemistry courses. The learning outcomes in the didactic design of the structure and physicochemical properties of ionic liquids are as follows: “Pre-service chemistry teachers can analyse and explain the relationship between the structure and physicochemical properties of ionic liquids and relate them to three levels of chemical representation (macroscopic, molecular, symbolic)”.

The profile and analysis of the View of Nature of Science and Technology (VNOST) and the learning barriers faced by pre-service chemistry teachers served as the basis for designing didactic situations. These situations reflect the pedagogical relationship (PR) between educators and students, including predictions of student responses and educator anticipations. The didactic design comprises seven parts, organised according to NOST aspects and aligned with ionic liquid content. The attached hypothetical didactic design on the relationship between the structure and physicochemical properties of ionic liquids is a revised version informed by analytical results and observations during implementation. The NOST-based didactic design for the concept of the relationship between the structure and physicochemical properties of ionic liquids is as follows:

### Didactic Design Based on the Characteristics of Science

Pre-service chemistry teachers' initial views on the characteristics of science are still dominated by the Has Merit category (61%) and by categories indicating that their understanding does not fully reflect science as a process of investigation aimed at explaining natural phenomena (Tairab, 2001; Venessa et al., 2019). Epistemological barriers are evident when students struggle to determine the appropriate chemical concept to explain the difference in melting points between molten salts and ionic liquids (Venessa et al., 2020). These findings indicate that students have not yet understood the essence of science as an investigative practice but tend to be oriented towards conceptual results (Cullinane & Erduran, 2023). From the perspective of the Nature of Science (NOS), this condition emphasises the importance of learning that places investigation at the core of the formation of scientific knowledge (Valencia Narbona et al., 2023).

In response to these conditions, a didactic situation was designed within the framework of Didactical Design Research (DDR) by adopting a phenomenon-based inquiry approach. Data on the melting points of salts and ionic liquids were used as empirical context to prompt students to observe, interpret, and formulate explanations for differences in the properties of the two compounds. This approach aims to shift the learning orientation from concept acceptance to knowledge construction through the investigation process, so that students can understand science as an exploratory activity that produces new knowledge (Daza-Perez & El-Hani, 2023; Valencia Narbona et al., 2023).

The implementation results indicate that, although ionic liquids are a new context, students have sufficient prior knowledge of the basic structure of ionic compounds. However, the explanations provided remain general and often require scaffolding through didactic anticipation to develop into more logical scientific arguments. This support has been shown to help students connect phenomena to relevant concepts and strengthen their scientific reasoning. The variety of student responses that emerged, such as the concepts of ionic bonds and intermolecular forces beyond the predictions designed in DDH, shows that the investigative process can open space for the formation of knowledge that is broader than that designed in the Hypothesis Didactic Design (DDH).

These findings indicate the need to revise the didactic design to better accommodate the diversity of student responses and to make the integration in core concepts more explicit. Thus, DDR functions not only as a framework for learning design but also as a reflective mechanism for refining pedagogical predictions

and didactic anticipations (Salsabila et al., 2025). Conceptually, this study offers novelty by demonstrating that integrating phenomenon-based inquiry into the DDR framework effectively transforms students' understanding of the characteristics of science, particularly by integrating concepts to interpret science as an investigative process that produces scientific explanations. Accordingly, the part of the revised didactic design that includes predicted student responses and pedagogical anticipations is presented in Table 1.

**Table 1.** Examples of alternative didactic designs based on the characteristics of science

<b>Learning Objectives:</b> Pre-service chemistry teachers can identify and explain fundamental concepts (including ion-ion interactions and electrostatic forces) in solids, melts, and ionic liquids.	
<b>Planned didactic situations</b> <i>The educator asks whether students have heard of ionic compounds and invites them to express their opinions on them.</i>	
<b>Predicting the Response of Students</b>	<b>Educator Anticipation</b>
<ol style="list-style-type: none"> <li>The student responds: <ul style="list-style-type: none"> <li>Ionic compounds are compounds formed from cations and anions.</li> <li>Ionic compounds are chemically bonded ionic compounds.</li> <li>Ionic compounds are compounds consisting of ions</li> </ul> </li> <li>Students have heard the term ionic compounds, but cannot explain their meaning</li> <li>Students find it difficult to provide scientific arguments</li> </ol>	<ol style="list-style-type: none"> <li>For responses 1 and 2, anticipation is directed at the components (cations and anions that are neutral overall) in ionic compounds and the bonds formed within them.</li> <li>For response 3, anticipation is carried out by asking, "What ions make up an ionic compound? Are their charges balanced?"</li> <li>If students cannot explain the meaning of ionic compounds, anticipation is directed towards examples of ionic salts that they are familiar with, such as NaCl, KCl, NaBr, etc.</li> </ol>
<i>To obtain the complete components of the didactic design and other related materials, readers may contact the author via email.</i>	

### Didactic design based on the aims of science

Pre-service chemistry teachers' initial views on the purpose of science were dominated by the Realistic category, which accounted for 73% (Venessa et al., 2020). This shows that most students view science as an effort to understand and explain natural phenomena. However, an analysis of learning barriers reveals that students still find it difficult to integrate the concept of chemical bonds to explain the formation and interaction of ions in ionic compounds (Venessa et al., 2020). The inability to connect macroscopic, submicroscopic, and symbolic representations shows that students' understanding of particle properties has not been coherently formed (Ni'mah et al., 2024). From the perspective of the Nature of Science (NOS), this condition holds that understanding the purpose of science is not sufficient to be declarative; it must be supported by the ability to use concepts to construct scientific explanations (Goren & Kaya, 2022).

In response to these findings, a didactic situation was developed within the framework of Didactical Design Research (DDR) to direct learning towards the meaning of science as a process of explaining and interpreting the continuous changes in nature and of understanding its characteristics. Visualization through instructional videos can help students understand the microscopic mechanisms underlying the formation of ionic bonds between sodium metal and chlorine gas, resulting in solid NaCl. Meanwhile, the guided inquiry approach encourages students to connect the stability of lattice energy to the solid-state form of NaCl. Based on the results of DDH implementation, students were generally able to relate the formation of the solid-phase NaCl structure to its energy stability. However, their explanations remained shallow, particularly regarding the balance of electrostatic forces, repulsive interactions between ions, and three-dimensional crystal structures. These findings indicate that visual representations alone are not sufficient to prevent misconceptions about ion size and crystal organization.

Thus, improvements to the didactic design focused on strengthening the epistemic aspects of the Nature of Science (NOS) by activating students' prior knowledge and by providing predictive questions before the

observation activity. This approach aimed to shift learning activities that had previously been oriented solely to visual reception towards a process of conceptual verification. In addition, learning questions are restructured to encourage mechanistic reasoning about how the balance of electrostatic forces and the arrangement of ions contribute to the energy of phase change during the formation of NaCl. Three-dimensional representation models are also used as conceptual scaffolding to help students understand the crystal structure spatially, not just in two dimensions (Gruber et al., 2020).

The results of this study indicate that didactic designs that combine prior knowledge activation, predictive questioning, and multimodal representations are more effective in supporting the construction of scientific explanations. Thus, DDR functions not only as a learning design framework but also as an epistemic mechanism for bridging declarative understanding to deeper scientific reasoning (Sjöström et al., 2020a). Conceptually, the novelty of this study lies in its assertion that strengthening science objectives through the explicit integration of NOS and representational scaffolding can shift students' understanding from merely knowing concepts to explaining phenomena through chemical mechanisms. Accordingly, the part of the revised didactic design that includes predicted student responses and pedagogical anticipations is presented in Table 2.

**Table 2.** Example of Alternative didactic designs based on the aims of science

<b>Learning Objectives:</b>	
<b>Knowledge:</b> Pre-service chemistry teachers can identify and explain fundamental concepts (including ion-ion interactions and electrostatic forces) in solids, melts, and ionic liquids.	
<b>Skills:</b> Pre-service chemistry teachers can establish active communication and interact in analysing ions in interactions in the solid structure and melting of ionic compounds	
<b>Planned didactic Situations</b>	
<i>Before the educator asks students to watch the video on crystal formation (Educator can use ACS videos or phet to demonstrate ionic bonding in NaCl Crystals), the educator asks students, based on the periodic table, to predict the size of Na atoms vs Na<sup>+</sup> ions and Cl atoms vs Cl<sup>-</sup> ions and explain their reasoning.</i>	
<b>Predicting the Response os Students</b>	<b>Educator Anticipation</b>
[1]The student responds: <ul style="list-style-type: none"> <li>a. The size of the Na atom is greater than that of Na<sup>+</sup> because Na releases 1 valence electron, causing its outer shell to disappear, while the size of the Cl<sup>-</sup> ion is greater than that of the Cl atom because it receives 1 electron.</li> <li>b. The Na<sup>+</sup> ion is greater than the Na atom because it is positive/has stronger energy</li> <li>c. The size of the Na and Cl atoms and the Na<sup>+</sup> and Cl<sup>-</sup> ions are the same because the atomic nucleus does not change.</li> <li>d. The Cl<sup>-</sup> ion is smaller than the Cl atom because the atomic nucleus attracts additional electrons more strongly.</li> </ul>	<ul style="list-style-type: none"> <li>a. If the response is like No. 1, students can be reinforced by asking them to write down the electron configuration for each atom to visualise the loss of the shell.</li> <li>b. If the response is like No. 2, students are asked to write down the electron configuration of each atom.</li> <li>c. If the response is like No. 3 and 4, direct students to the concept of electron shells and the repulsive force between electrons.</li> <li>d. If the answer is incorrect or unclear, students are directed back to look at the position of the element in the periodic table and understand the concept of electron shells and electron repulsion.</li> </ul>
[2]The student is merely guessing without a clear reason.	
<i>To obtain the complete components of the didactic design and other related materials, readers may contact the author via email.</i>	

### Didactic Design based on the aspects of scientific research

VNOST pre-service chemistry teachers' views on scientific research are still dominated by the Has Merit category (61%), while only 39% reach the Realistic category (Nurhadi et al., 2020; Venessa et al.,

2019). These findings indicate that students do not fully understand scientific research as a process of testing explanations for natural phenomena, but rather as an activity of collecting data or drawing factual conclusions (Imafuku et al., 2015; Solikha, 2022). This condition reflects a weak understanding of the Nature of Science (NOS), particularly in its tentative, inferential, and theory-laden dimensions, which can limit the development of science literacy among prospective chemistry educators. Theoretically, learning should showcase scientists' epistemic practices so that students understand that scientific knowledge is constructed through evidence-based interpretation, not merely the results of observation (Venessa et al., 2019; M. Wang et al., 2022).

The analysis of learning barriers indicates the presence of epistemological barriers in understanding ionic bonds, particularly in integrating macroscopic, submicroscopic, and symbolic representations (Venessa et al., 2020). Students often struggle to explain the relationships among structure, ion mobility, electrostatic force strength, and bond energy in NaCl and ionic liquids (Kapici, 2023; Rahmawati et al., 2022). Misconceptions that arise, such as the assumption that interactions do not occur in solid crystals or the difficulty in distinguishing ion mobility in ionic compounds, indicate that students' conceptual understanding remains fragmented. These findings confirm that chemistry learning needs to go beyond mastery of concepts to the development of scientific thinking that emphasizes the relationships among evidence, models, and explanations (Irwanto, 2023).

In response to these conditions, didactic design needs to be developed within the framework of Didactical Design Research (DDR), with empirical evidence and modeling at the center of learning. The presentation of data on the structure of NaCl obtained by X-ray diffraction and its comparison with ionic liquid structures demonstrates how scientific models are produced through research practices (Goren & Kaya, 2022). Guided discussions and leading questions are used as didactic anticipations to help students relate structural symmetry, ion size, interionic distance, and electrostatic forces as the basis for scientific explanations (Academy, 2025). This approach represents an explicit integration between NOS and modeling practices in chemistry learning.

The results of the implementation show that this didactic support shifted students' understanding from descriptive to explanatory. Students successfully identified that the more symmetrical structure of NaCl produces stronger electrostatic forces and requires more energy to break bonds than ionic liquids. They also concluded that ion size, molecular shape, and interionic distance determine the physical properties of ionic compounds. These findings confirm the contribution of evidence-based didactic design in reducing conceptual barriers and facilitating students' development of views towards the Realistic category. Conceptually, this study is novel in demonstrating that the explicit integration of NOS into the DDR framework effectively transforms students' understanding from a fact-oriented to an explanation-based approach to scientific reasoning. Accordingly, the part of the revised didactic design that includes predicted student responses and pedagogical anticipations is presented in Table 3.

**Table 3.** Example of Alternative didactic designs based on the aspect of scientific research

---

**Learning Objectives:**

**Knowledge:** Pre-service chemistry teachers can analyze the relationship between electrostatic forces and the physical properties of ionic compounds and explain how changes in cation and anion size affect the magnitude of electrostatic forces.

**Skills:** Pre-service chemistry teachers can establish active communication and interaction by analyzing ion interactions in the solid and molten states of ionic compounds and examining how changes in cation and anion sizes affect the physicochemical properties of ionic liquids.

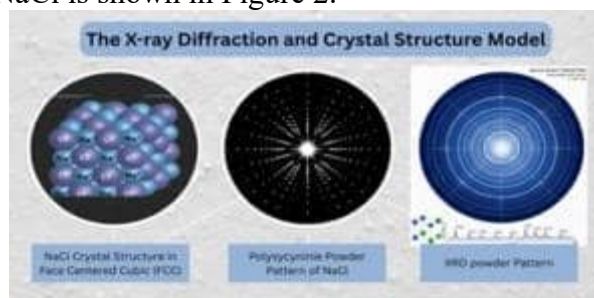
---

---

## Planned Didactic Situation

### *Educators provide scientific research facts regarding the determination of the structure of NaCl:*

Educators explain that scientists determine the structure of NaCl using X-ray diffraction (XRD). XRD analysis is often used to analyse the presence of a compound. This is done by observing the pattern of light diffraction from the crystal sample. These diffraction patterns are produced by light diffracted by the atomic arrangement in the crystal lattice of the observed sample (Ohno & Furukawa, 1981). The principle of XRD is that each compound, composed of atoms forming specific planes, produces characteristic reflection or diffraction patterns. The X-ray diffraction pattern of NaCl is shown in Figure 1, and the crystal structure of NaCl is shown in Figure 2.



**Figure 2.** Structure Image and X-ray Diagram for NaCl Crystal (Libretexts, 2021; Open Lab, 2018) (edited and combine data by gemini AI)

---

*To obtain the complete components of the didactic design and other related materials, readers may contact the author via email.*

---

## Didactic Design based on the aspect of Scientific Knowledge

Pre-service chemistry teachers' views on scientific knowledge are dominated by the Realistic category (96%) (Venessa et al., 2019). These results indicate that the ionic fluid-based discourse in the questionnaire is effective in helping students understand scientific knowledge as a construct built through empirical evidence, interpretation, and scientists' perspectives. Furthermore, this finding confirms that authentic learning contexts can strengthen students' understanding of the nature of scientific knowledge within the Nature of Science (NOS) (Valente et al., 2022). However, it is important to note that the high percentage in the Realistic category does not necessarily indicate the depth of conceptual understanding. In fact, the results of the learning barriers analysis show that students have difficulty relating the influence of electrostatic forces to the melting point of ionic compounds. Specifically, students often struggle to integrate submicroscopic and symbolic representations when explaining ionic interactions and how cation and anion sizes influence electrostatic forces and the melting points of ionic compounds (Valente et al., 2022).

These barriers indicate that students have not yet fully developed clear mental models of the material's structure (Prasetya Cahya & Surya, 2025). Misunderstandings, such as believing that electrostatic forces in ionic liquids are stronger than in salts, indicate that students struggle to connect ideas such as crystal shape, ion size, and ion spacing with the strength of electrostatic forces. The more regular crystal structure of NaCl means ions are closer together, and the forces between them are stronger. In contrast, the large and complex cations in ionic liquids make the forces with anions weaker (de Souza et al., 2022; Gebbie et al., 2017). These results indicate that scientific knowledge should not be merely memorised. It also requires connecting evidence, models, and explanations (Astuti et al., 2022).

Based on this, the didactic design was developed within the framework of Didactical Design Research (DDR), with empirical evidence and modelling at the centre of the learning process. The presentation of Paul Walden's research history and the visualisation of the structures of NaCl melt and ionic liquids demonstrated how scientific knowledge is generated through research practices. Guided discussions and leading questions were used as didactic anticipations to help students understand the relationship between structural symmetry, ion mobility, electrostatic force strength, and bond energy. The integration of

modelling in this empirical context not only supports conceptual understanding but also strengthens the epistemic dimension of NOS (Lazenby et al., 2020).

The implementation results indicate a shift in students' reasoning quality from intuitive responses to concept-based explanations. Students identified that stronger electrostatic forces reduce ion mobility and require more energy to overcome the electrostatic potential barrier. In addition, ion size, molecular shape, and interionic distance affect the physical properties of ionic compounds. These findings indicate that didactic support through modelling and analysis of empirical evidence is effective in reducing conceptual barriers and deepening students' understanding of scientific knowledge (Sjöström et al., 2020b; Takowa et al., 2025). Conceptually, this study offers novelty by showing that the explicit integration of empirical context, modelling, and epistemic practices within the DDR framework can strengthen NOS understanding even among students who have demonstrated Realistic views, transforming mere recognition of science into the ability to explain phenomena scientifically. Accordingly, the part of the revised didactic design, including predicted student responses and pedagogical anticipations, is provided in Table 4

**Table 4.** Example of Alternative didactic designs based on the aspect of scientific research

---

**Learning Objective**

**Knowledge:** Pre-service chemistry teachers can analyze how changes in cation and anion size and shape affect the structure of ionic liquids and how these changes relate to their physicochemical properties.

**Skills:** Pre-service chemistry teachers can communicate and interact effectively when analyzing how ion size and structural symmetry influence the physicochemical properties of ionic liquids.

---

**Planned Didactic Situation**

The educator shows a picture of Paul Walden, the scientist who first introduced ionic liquids.



Paul Walden reported the physical properties of ethylammonium nitrate ( $[\text{EtNH}_3][\text{NO}_3]$ ), which melts at 13–14 °C and is formed by the neutralisation of ethylamine with nitric acid. Ethylammonium nitrate is the first compound to demonstrate that ionic liquids can melt below room temperature. Additionally, ionic liquids were first investigated as an electrochemical medium. The ionic liquid used was a mixture of Aluminium(III) chloride with organic halides, such as 1-ethylimidazolium chloride ( $[\text{C}_2\text{mim}]\text{Cl}$ ), which melts at room temperature. Another fact is that in 1982, Wilkes, Hussey, and others reported on another ionic liquid, alkyl imidazolium coro alumina, which is easier to synthesise and has been used in many fields. The scientific potential for ionic liquid research is almost limitless. Over 1,500 ionic liquids have been reported in scientific literature, and over 2,500 papers on ionic liquids were published in 2008 (Freemantle, 2010).

*..... To obtain the complete components of the didactic design and other related materials, readers may contact the author via email.*

---

**Didactic design based on the aspect of scientific knowledge**

Pre-service chemistry teachers' views on scientific knowledge are dominated by the Realistic category (96%) (Venessa et al., 2019). These results indicate that the ionic fluid-based discourse in the questionnaire is effective in helping students understand scientific knowledge as a construct built through empirical evidence, interpretation, and scientists' perspectives. Furthermore, this finding confirms that authentic learning contexts can strengthen students' understanding of the nature of scientific knowledge within the

Nature of Science (NOS) (Valente et al., 2022). However, it is important to note that the high percentage in the Realistic category does not necessarily indicate the depth of conceptual understanding. In fact, the learning barriers analysis shows that students have difficulty relating the influence of electrostatic forces to the melting points of ionic compounds. Specifically, students often struggle to integrate submicroscopic and symbolic representations when explaining ionic interactions and how cation and anion sizes influence electrostatic forces and the melting points of ionic compounds (Valente et al., 2022).

These barriers indicate that students have not yet fully developed clear mental models of the material's structure (Prasetya Cahya & Surya, 2025). Misunderstandings, such as believing that electrostatic forces in ionic liquids are stronger than in salts, indicate that students struggle to connect ideas about crystal shape, ion size, and ion spacing to the strength of electrostatic forces. The more regular crystal structure of NaCl means ions are closer together, and the forces between them are stronger. In contrast, the large and complex cations in ionic liquids make the forces with anions weaker (de Souza et al., 2022; Gebbie et al., 2017). These results indicate that scientific knowledge should not be merely memorised. It also requires connecting evidence, models, and explanations (Astuti et al., 2022).

Based on this, the didactic design was developed within the framework of Didactical Design Research (DDR), with empirical evidence and modelling at the centre of the learning process. The presentation of Paul Walden's research history and the visualisation of the structures of NaCl melt and ionic liquids demonstrated how scientific knowledge is generated through research practices. Guided discussions and leading questions were used as didactic anticipations to help students understand the relationship between structural symmetry, ion mobility, electrostatic force strength, and bond energy. The integration of modelling in this empirical context not only supports conceptual understanding but also strengthens the epistemic dimension of NOS (Lazenby et al., 2020).

The implementation results indicate a shift in students' reasoning quality from intuitive responses to concept-based explanations. Students identified that stronger electrostatic forces reduce ion mobility and require more energy to overcome the electrostatic potential barrier. In addition, ion size, molecular shape, and interionic distance affect the physical properties of ionic compounds. These findings indicate that didactic support through modelling and analysis of empirical evidence is effective in reducing conceptual barriers and deepening students' understanding of scientific knowledge. (Sjöström et al., 2020b; Takowa et al., 2025). Conceptually, this study offers novelty by showing that the explicit integration of empirical context, modelling, and epistemic practices within the DDR framework can strengthen NOS understanding even among students who have demonstrated Realistic views, transforming mere recognition of science into the ability to explain phenomena scientifically. Accordingly, the part of the revised didactic design that includes predicted student responses and pedagogical anticipations is presented in Table 5.

**Table 5.** Example of Alternative Didactic Designs for Technological Characteristics

<b>Learning Objectives</b>	
<b>Knowledge:</b> Pre-service chemistry teachers can explain how changes in cation and anion size affect the electrostatic forces in ionic compounds.	
<b>Skills:</b> Pre-service chemistry teachers can examine the implementation of science and technology in ionic liquids.	
<b>Planned Didactic Situation</b>	
<i>The educator asks students to identify technologies around them that are highly advanced and continually evolving.</i>	
<b>Predicted Responses of Pre-service Chemistry Teachers</b>	<b>Educator Anticipation</b>
1. Students name examples of technologies around them, such as mobile phones, laptops, tablets, headsets, LED lights, printers, power banks, etc.	1. If the responses align with predictions 1, 2, and 3, the educator guides students toward something created or developed from previous technologies. 2. If all responses are tools, devices, or instruments, the educator guides students towards

- |   |  |
|---|--|
| 2. Students name technologies that use artificial intelligence, such as robots, holograms, 3D printers, virtual games, etc. | technological innovations that continue to evolve from previous technologies (e.g., mobile phone batteries, which were initially large and used lithium salt as an electrolyte conductor, have been innovated to use implantable batteries and ionic liquids as electrolyte components). |
| 3. Students mention technologies in the laboratory, such as green solvents, microscopes, spectroscopy, etc.                 |  |

*..... To obtain the complete components of the didactic design and other related materials, readers may contact the author via email*

#### Didactic design based on aspects of Scientific Theory

Pre-service chemistry teachers' views on scientific theory remain dominated by the Has Merit category (35%), with 30% in the Realistic category, and the remainder in the Naïve category. (Venessa et al., 2019) These findings indicate that students do not yet fully understand scientific theory as an evidence-based explanation constructed through the scientific process, and that it is tentative. Some still view theory as conjecture, while others see it as merely an agreement among scientists, with little connection to empirical data (Nurhadi et al., 2020; Venessa et al., 2019) This condition emphasises the importance of learning that explicitly links evidence to theory construction, so that students can view theory as an explanatory tool rather than merely a scientific consensus (Svendsen, 2021).

Learning obstacles become increasingly apparent when students analyse the relationship between changes in cation size and shape and the physical properties of ionic liquids. (Venessa et al., 2020) Students often struggle to explain how adding alkyl groups leads to larger structures, thereby increasing the distance between ions and weakening electrostatic interactions. Students also find it difficult to represent phenomena at the symbolic and submicroscopic levels that influence their understanding of the relationship between structure and the physicochemical properties of ionic liquids. (R. Wang et al., 2022; Yeboah et al., 2024).

In response to these conditions, a didactic design was developed within the framework of Didactical Design Research (DDR), placing empirical data analysis as the foundation for building theoretical understanding. Students were guided to interpret data on the melting points of tetraalkylammonium bromide and [Emim]X salts to understand the relationships among physical properties, ion size, electrostatic forces, and structural stability. Through guided discussions, learning served as a didactic anticipation, helping students construct evidence-based explanations while integrating macroscopic, submicroscopic, and symbolic representations. This approach confirms that DDR plays an important role in shifting students' understanding from mere description to theoretical reasoning, a hallmark of scientific practice (Riley & Dutta, 2024).

The implementation results show that, although students initially had difficulty interpreting trends in the data, scaffolding support through conceptual questions guided them to identify that increases in cation or anion size are associated with weaker electrostatic forces and lower melting points (Dong et al., 2014). ability to explain this structure–energy–property relationship indicates a shift from intuitive responses to more theory-based explanations. Thus, didactic designs that focus on data interpretation not only help reduce conceptual barriers but also strengthen students' understanding of scientific theory as an explanatory construct (Sjöström et al., 2020a). Conceptually, this study offers novelty by demonstrating that integrating empirical data analysis into the DDR framework effectively transforms students' interpretation of scientific theory as an explanatory framework for chemical phenomena. Accordingly, the part of the revised didactic design that includes predicted student responses and pedagogical anticipations is presented in Table 6.

**Table 6.** Example of Alternative Didactic Designs in Scientific Theory Aspects

#### **Learning Objectives**

**Knowledge:** Pre-service chemistry teachers can analyze the effect of variations in alkyl length on cations on the physicochemical properties of ionic liquids

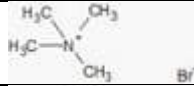
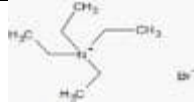
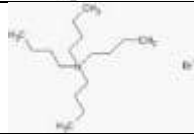

**Skills:** Pre-service chemistry teachers can make appropriate decisions in the context of solving problems related to the relationship between structure and the physicochemical properties of ionic liquids

## Planned Didactic Situation

Educators present data tables from research conducted by scientists.

To date, journals related to ionic liquids have continued to grow, and interest in them has increased. Below are the melting point data for the ionic liquid tetraalkylammonium bromide from various experiments.

**Table 1.** Melting point of tetraalkylammonium bromide salt

Kation	Titik leleh (°C)	Gambar
Tetramethylammonium bromide salt	>300	
Tetraethylammonium bromide salt	284	
Tetrabutylammonium bromide salt	124-128	
Tetraheksilamonium bromide salt	99-100	
<i>..... To obtain the complete components of the didactic design and other related materials, readers may contact the author via email</i>		

## Didactic design based on the aspect of the relationship between science and technology

Pre-service chemistry teachers' views on the relationship between science and technology show a relatively balanced distribution across the Merit (39%) and Realistic (39%) categories, with the remaining 17% falling into the Naïve category (Venessa et al., 2019). These findings indicate that although some students have recognised the interconnection between the two, there remains a tendency to view science and technology as separate. This perspective is inconsistent with the Nature of Science (NOS) framework, which views science and technology as mutually reinforcing, with technological advances driving scientific inquiry and scientific findings informing technological development (Gardner, 2010). Thus, learning needs to emphasise the epistemic relationship between the two so that students do not view technology solely as a final product but as part of scientific practice (López-Banet & Martínez-Carmona, 2021).

Conceptual barriers arise when students are asked to analyse the symmetry of ionic liquid structures (Venessa et al., 2020). Students tend to find it difficult to explain the geometry of the [Emim]<sup>+</sup> cation and its impact on charge delocalisation. This indicates that their understanding of the relationship between the structure and the physicochemical properties of ionic liquids remains limited. In fact, an increase in the size and complexity of cations can cause a more disordered structure, a more dispersed charge distribution, and a tendency for the melting point to decrease (Dong et al., 2014; R. Wang et al., 2022). The absence of this reasoning confirms that students have not fully integrated the concepts of molecular geometry, polarisation, and electrostatic interactions as the basis for scientific explanations. These results reinforce the argument that understanding the relationship between science and technology requires conceptual depth, not just an introduction to applications. (Rahmawati et al., 2022).

In response to these conditions, didactic designs were developed within the framework of Didactical Design Research (DDR), emphasising the two-way relationship between science and technology as the

foundation for learning. The presentation of examples of ionic liquid applications in real-world contexts illustrated how chemical principles are used in materials engineering. (Hernani et al., 2016; Riley & Dutta, 2024). In addition, conceptual scaffolding focused on structural geometry, ion size, electron delocalisation, and polarisation effects was designed to help students construct concept-based explanations. This approach positions technology as both a concrete representation of chemical theory and a context for developing scientific reasoning. (Rahmawati et al., 2022).

The implementation results indicate that students initially had difficulty distinguishing between symmetrical and asymmetrical structures in two organic salts. However, after didactic support, students identified that tetramethylammonium bromide had a more symmetrical structure and the potential to exhibit a higher melting point. Nevertheless, the relationship between the larger cation size in [Emim]Br and the resulting decreased symmetry and lower melting point remains poorly understood. This indicates the need to further strengthen the integration of structure and physicochemical properties in ionic liquids. Conceptually, this study offers novelty by demonstrating that integrating science–technology relationships within the DDR framework not only broadens understanding of NOS but also facilitates students' transition from recognising technology to explaining the scientific basis underpinning material innovation. Accordingly, the part of the revised didactic design that includes predicted student responses and pedagogical anticipations is presented in Table 7.

**Table 7.** Alternative Didactic Designs on the aspect of the relationship between science and technology

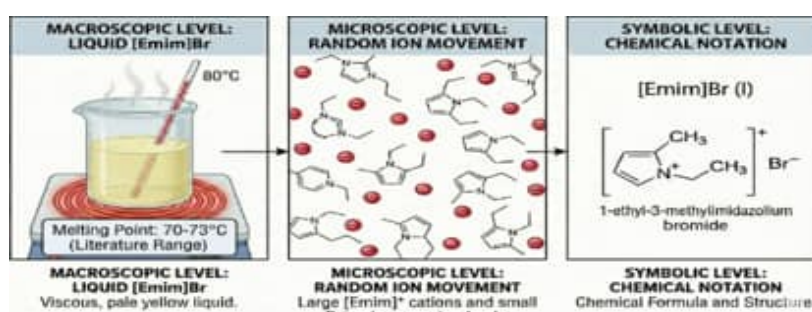
**Learning Objective:**

**Knowledge:** Pre-service chemistry teachers can analyze how structural symmetry affects the physical properties of ionic liquids.

**Skills:** Pre-service chemistry teachers can make appropriate decisions when solving problems related to the relationship between the structure of ionic liquids and their physicochemical properties.

**Planned didactic situations:**

Educators provide examples of ionic liquids in everyday technological applications. One application of ionic liquids in technology is as green solvents. Ionic liquids are referred to as green solvents because they are non-volatile, exhibit good photoelectrochemical performance, are stable and environmentally friendly, and can reduce potential environmental toxicity (Freemantle, 2010). *The educator shows the structure of one of the ionic liquids used as a solvent. The teacher asks, "Why do you think green solvents are important to replace the solvents that were used previously?"*



**Figure 1.** Ionic liquid 1-alkyl-3-methylimidazolium Bromide (generated by Gemini AI based on relevant source)

..... *To obtain the complete components of the didactic design and other related materials, readers may contact the author via email*

Potential of Didactic Design in Concept Mastery Among Pre-service Chemistry Teachers

Implementing a didactic design based on the seven NOST aspects to teach the relationship between structure and the physicochemical properties of ionic liquids has the potential to enhance conceptual mastery among pre-service chemistry teachers. A comparison of pre-test and post-test results shows a

significant improvement across all indicators of conceptual understanding. In detail, the percentages of student responses that matched the expected answers before and after learning, using the hypothetical didactic design, are presented in Table 8.

**Table 7.** Percentage of Correct Answers by Prospective Chemistry Teachers Before and After Instruction

Section Question	Pretest Average	Post-test Average
1	13%	91%
2	70%	88%
3	61%	90%
4	35%	61%
5	39%	61%
6	48%	61%
7	23%	77%

The most significant improvement occurred in the first section, rising from 13% to 91%, in which students were able to identify essential chemistry concepts that explain how structural changes affect the physicochemical properties of ionic liquids, particularly differences in melting points. Sections 4, 5, and 6 showed more modest gains (35%→61%, 39%→61%, 48%→61%), reflecting the persistently complex nature of concepts related to electrostatic forces, alkyl chain variation, and structural symmetry, which require deeper scaffolding than a single implementation cycle can provide. The results of this study indicate that, through the implementation of the designed didactic approach, students actively construct their knowledge through structured learning experiences (Suryadi, 2013).

The present findings are consistent with and extend previous research in chemistry education. Venessa et al. (2019) and Nurhadi et al. (2020) found that pre-service chemistry teachers predominantly held Has Merit views across Nature of Science Teaching (NOST) aspects prior to instruction. This study confirms and expands upon these results by demonstrating measurable shifts following structured didactic intervention. In terms of conceptual mastery, Riley and Dutta (2024) showed that inquiry-based ionic liquid modules significantly improved undergraduate students' ability to connect molecular structure to physicochemical properties. This outcome parallels the improvements observed in Sections 1, 2, and 3 of the current study. Additionally, García-Carmona (2022) and Cullinane and Erduran (2023) highlighted the necessity of explicitly integrating Nature of Science (NOS) into instructional design to facilitate a transition from declarative to explanatory understanding among pre-service teachers. This aligns with the function of NOST aspects as the epistemic foundation of the didactic design implemented in this research. The use of didactic anticipation as a scaffolding mechanism further supports the theoretical framework proposed by Suryadi (2019), which posits that structured didactic situations explicitly addressing learning obstacles foster more meaningful and systematic conceptual development among pre-service teachers.

Based on these findings, the designed didactic situations not only enhance students' conceptual mastery but also encourage systematic, structured thinking. Didactic situations developed gradually through guided questions, didactic anticipation, and group discussions enable students to build their understanding both independently and collaboratively. Students also become able to comprehend how variations in the alkyl chain length of cations affect the melting point of ionic liquids, as well as the influence of van der Waals interactions and structural bulkiness in explaining factors that influence the physicochemical properties of ionic liquids. Thus, this didactic design that relates structure to the physicochemical properties of ionic liquids has the potential to overcome learning obstacles while fostering independent thinking among prospective chemistry teachers in they understand contemporary chemistry contexts, such as ionic liquid technology.

Although the results of this study are promising, several limitations must be acknowledged. This study involved only 23 pre-service chemistry teachers from a single institution in South Sumatra, which limits the generalizability of the findings. The didactic design was also implemented in only one cycle, so the revised Empirical Didactic Design has not yet been validated through multiple implementation cycles as

recommended by the DDR framework (Suryadi, 2019; Fauzi & Suryadi, 2020). In addition, the absence of a control group means that the observed improvements cannot be fully attributed to the didactic design. Future research is recommended to employ multi-site implementation, larger samples, and multiple DDR cycles to further validate and refine this didactic design.

## Conclusion

The research findings show that developing pre-service chemistry teachers' views of the Nature of Science and Technology (NOST) and their mastery of concepts requires an instructional design that connects science and technology. Based on initial results from the View of Nature of Science and Technology (VNOST) and learning obstacles experienced by students, strengthening VNOST understanding and the context of ionic liquids cannot be achieved solely through conceptual mastery. Explicit integration of scientific practice, knowledge construction, theory, and current technological contexts is necessary in the chemistry learning process. These findings also indicate that, although some realistic views emerge in NOST aspects, epistemological barriers related to the context of ionic liquids arise from fragmented understanding among empirical evidence, representational models, and conceptual explanations. Through the Didactical Design Research (DDR) framework, the developed didactical design has the potential to reduce learning barriers and improve chemistry concept mastery by encouraging students to think systematically in building connections between the structure and physicochemical properties of ionic liquids.

The systematically developed didactical design connects the characteristics of science as an investigative process, the aim of science as the construction of explanations, scientific research as epistemic practice, scientific theories as explanatory frameworks, and technology as a scientific application. Thus, students' understanding can shift from declarative knowledge toward scientific reasoning. The integration of NOST characteristics in the didactic design serves as an epistemic mechanism that transforms students' mindsets from merely mastering concepts to explaining phenomena scientifically. Approaches based on phenomena, modeling, inquiry, and the technological context of ionic liquids not only deepen conceptual understanding but also strengthen reasoning and explanation, which are the foundation of scientific and technological literacy for prospective chemistry teachers. This research contributes to broadening perspectives in chemistry education through a proposed integrative NOST-based framework and systematic learning.

The designed didactical approach has significant potential for developing concept mastery in prospective chemistry teachers, especially on the topic of the relationship between structure and the physicochemical properties of ionic liquids. The overall average increase in pretest-posttest scores was 34.3%, with the largest improvement in understanding of ionic bonding concepts and lattice energy, from 13% to 91%. The success of this didactic design is influenced by its systematic structure, through stepwise questioning, didactic anticipation, and group discussions, thereby enabling students not only to actively and independently build conceptual mastery but also to develop systematic, structured thinking skills. Therefore, a hypothesis-based didactic design that considers students' learning obstacles can serve as an effective alternative instructional approach to enhance pre-service chemistry teachers' understanding of complex chemistry concepts (Yusra et al., 2025).

## References

- Academy, I. (2025). *2.3C Ionic Bond Strength and Electrostatic Forces- Pre AP Chemistry Study Notes*. <https://www.iitianacademy.com/ap-exam/pre-ap-chemistry-revision-resources/2-3c-ionic-bond-strength-and-electrostatic-forces-pre-ap-chemistry-study-notes/>
- Astuti, S. R. D., Sari, A. R. P., Amelia, R. N., & Karlinda, K. (2022). Instrumen Penilaian Terintegrasi : Pengukuran Kemampuan Berpikir Kritis dan Keterampilan Sains Siswa Pada Materi Larutan Elektrolit dan Nonelektrolit. *JURNAL TARBIYAH*, 29(2), 340. <https://doi.org/10.30829/tar.v29i2.1858>

- Ba, Z., Meng, K., Liu, L., & Zhang, Y. (2025). How science-technology interactions affect technological innovation: the moderating role of topic divergence. *Humanities and Social Sciences Communications* 2025 12:1, 12(1), 1849-. <https://doi.org/10.1057/s41599-025-06002-4>
- Badgujar, K. C., Badgujar, V. C., & Bhanage, B. M. (2022). Recent update on use of ionic liquids for enzyme immobilization, activation, and catalysis: A partnership for sustainability. *Current Opinion in Green and Sustainable Chemistry*, 36, 100621. <https://doi.org/10.1016/j.cogsc.2022.100621>
- Cullinane, A., & Erduran, S. (2023). Nature of Science in Preservice Science Teacher Education—Case Studies of Irish Pre-service Science Teachers. *Journal of Science Teacher Education*, 34(2), 201–223. <https://doi.org/10.1080/1046560X.2022.2042978>
- Daza-Perez, E., & El-Hani, C. N. (2023). Pesquisa de Design Educacional no Desenvolvimento de uma Inovação Didática de Ciências Naturais:: Reflexões sobre Questões Procedimentais. *Cadernos de Educação Tecnologia e Sociedade*, 16(se1), 20–27. <https://doi.org/10.14571/brajets.v16.nse1.20-27>
- de Souza, J. P., Pivnic, K., Bazant, M. Z., Urbakh, M., & Kornyshev, A. A. (2022). Structural Forces in Ionic Liquids: The Role of Ionic Size Asymmetry. *The Journal of Physical Chemistry B*, 126(6), 1242–1253. <https://doi.org/10.1021/ACS.JPCB.1C09441>
- Dong, K., Wang, Q., Lu, X., Zhou, Q., Zhang, S., Wang, J., Wang, H., Wang Hui, Gurau, G., Roger, R. D., Mu, T., Han, B., Hu, Y., Peng, X., & Li, H. (2014). *Structures and Interactions of Ionic Liquids* (S. Zhang, J. Wang, X. Lu, & Q. Zhou, Eds.). Springer Heidelberg New York Dordrecht. <http://www.springer.com/series/430>
- Dorsah, P. (2020). Pre-Service Teachers' View of Nature of Science (NOS). *European Journal of Education Studies*, (6), 124–146. <https://doi.org/https://doi.org/10.5281/ZENODO.3365422>
- Erika, E., Sumarni, S., & Adiasuty, N. (2022). Didactic Design Analysis Of Quadrilateral Learning In The Term Of Interactive Media Based On Adobe Flash Through Contextual Teaching And Learning Approach. *Mathline : Jurnal Matematika Dan Pendidikan Matematika*, 7(2). <https://doi.org/10.31943/mathline.v7i2.224>
- Fauzi, I., & Suryadi, D. (2020). Inventa : Jurnal Pendidikan Guru Sekolah Dasar Didactical Design Research untuk Mengembangkan Kompetensi Pedagogik Guru di Sekolah Dasar. *Jurnal Pendidikan Guru Sekolah Dasar*, 04(1), 58–67. [http://jurnal.unipasby.ac.id/index.php/jurnal\\_inventa](http://jurnal.unipasby.ac.id/index.php/jurnal_inventa)
- Freemantle, M. (2010). An Introduction to Ionic Liquids. *Choice Reviews Online*, 47(12), 47-6874-47–6874. <https://doi.org/10.5860/CHOICE.47-6874>
- García-Carmona, A. (2022). Improving Preservice Primary Teachers' Understanding of the Nature of Methods of Science Through Reflective Reading of News Articles. *Science & Education*, 32(6), 1. <https://doi.org/10.1007/s11191-022-00338-y>
- Gebbie, M. A., Smith, A. M., Dobbs, H. A., Lee, A. A., Warr, G. G., Banquy, X., Valtiner, M., Rutland, M. W., Israelachvili, J. N., Perkin, S., & Atkin, R. (2017). Long range electrostatic forces in ionic liquids. *Chemical Communications*, 53(7), 1214–1224. <https://doi.org/10.1039/c6cc08820a>
- Goren, D., & Kaya, E. (2022). How is Students' Understanding of Nature of Science Related with Their Metacognitive Awareness? *Science & Education*, 32(5), 1. <https://doi.org/10.1007/s11191-022-00381-9>
- Gruber, C., James, A., Berchtold, J. T., Wood, Z. J., Scott, G. E., & Alghoul, Z. (2020). Interactive Unit Cell Visualization Tool for Crystal Lattice Structures. *Journal of Chemical Education*, 97(7), 2020–2024. <https://doi.org/10.1021/acs.jchemed.9b01207>
- Guerra, M. H. F. S., Vasconcelos, A. K. P., Sampaio, C. de G., Sampaio, C. de G., Saldanha, G. C. B., & Saldanha, G. C. B. (2019). Ensaio sobre os Obstáculos Epistemológicos presentes em estratégias

- metodológicas no Ensino de Química, uma revisão da bibliografia. *Research, Society and Development*, 8(7), e15871113–e15871113. <https://doi.org/10.33448/rsd-v8i7.1113>
- Ha, H., Park, W., & Song, J. (2023). Preservice Elementary Teachers' Socioscientific Reasoning During a Decision-Making Activity in the Context of COVID-19. *Science and Education*, 32(6), 1869–1886. <https://doi.org/10.1007/s11191-022-00359-7>
- Hernani, Mudzakir, A., & Sumarna, O. (2016). Ionic liquids material as modern context of chemistry in school. *Jurnal Pendidikan IPA Indonesia*, 5(1), 63–68.
- Imafuku, R., Saiki, T., Kawakami, C., & Suzuki, Y. (2015). How do students' perceptions of research and approaches to learning change in undergraduate research? *International Journal of Medical Education*, 6, 47–55. <https://doi.org/10.5116/ijme.5523.2b9e>
- Irwanto, I. (2023). Improving Pre-service Chemistry Teachers' Critical Thinking and Science Process Skills Using Research-Oriented Collaborative Inquiry Learning. *Journal of Technology and Science Education*, 13(1), 23–35. <https://doi.org/10.3926/JOTSE.1796>
- Kapici, H. Ö. (2023). From Symbolic Representation to Submicroscopic One: Preservice Science Teachers' Struggle with Chemical Representation Levels in Chemistry. *International Journal of Research in Education and Science*, 9(1), 134–147. <https://doi.org/10.46328/ijres.3122>
- Lazenby, K., Stricker, A., Brandriet, A., Rupp, C. A., Mauger-Sonnek, K., & Becker, N. M. (2020). Mapping undergraduate chemistry students' epistemic ideas about models and modeling. *Journal of Research in Science Teaching*, 57(5), 794–824. <https://doi.org/10.1002/tea.21614>
- Libretexts. (2021). *X-ray diffraction, Bragg's law and Laue equation - Engineering LibreTexts*. [https://Eng.Libretexts.Org/Bookshelves/Materials\\_Science/Supplemental\\_Modules\\_\(Materials\\_Science\)/Electronic\\_Properties/X-Ray\\_diffraction\\_Bragg's\\_law\\_and\\_Laue\\_equation](https://Eng.Libretexts.Org/Bookshelves/Materials_Science/Supplemental_Modules_(Materials_Science)/Electronic_Properties/X-Ray_diffraction_Bragg's_law_and_Laue_equation). [https://eng.libretexts.org/Bookshelves/Materials\\_Science/Supplemental\\_Modules\\_\(Materials\\_Science\)/Electronic\\_Properties/X-ray\\_diffraction\\_Bragg's\\_law\\_and\\_Laue\\_equation](https://eng.libretexts.org/Bookshelves/Materials_Science/Supplemental_Modules_(Materials_Science)/Electronic_Properties/X-ray_diffraction_Bragg's_law_and_Laue_equation)
- Liman, S., & Kaptan, F. (2024). Socioscientific Issues in Science Education. In *Current Studies in Educational Disciplines*.
- López-Banet, L., & Martínez-Carmona, M. (2021). Preservice Chemistry Teachers' Epistemic Beliefs After a Student-Centred Approach Training Programme. *Eurasia Journal of Mathematics, Science and Technology Education*, 17(12). <https://doi.org/10.29333/ejmste/11359>
- Mafugu, T., Tsakeni, M., & Jita, L. C. (2022). Preservice Primary Teachers' Perceptions of STEM-Based Teaching in Natural Sciences and Technology Classrooms. *Canadian Journal of Science, Mathematics and Technology Education*, 22(4), 898–914. <https://doi.org/10.1007/s42330-022-00252-z>
- Ni'mah, F., Sari, A. R. P., Anggraeni, M. E., & Theasy, Y. (2024). Analisis Kualitatif Kesalahan Konseptual Senyawa Ionik dan Senyawa Kovalen dalam Argumentasi Mahasiswa pada Laporan Praktikum Kimia Dasar. *Jurnal Ilmiah Kanderang Tingang*, 15(2), 343–358. <https://doi.org/10.37304/jikt.v15i2.344>
- Nurhadi, A. R., Hernani, H., Musthapa, I., Devita, R., & Somadipraja, F. (2020). *How the Profile of Students' Views on the Nature of Science and Technology?*
- Ohno, H., & Furukawa, K. (1981). X-ray diffraction analysis of molten NaCl near its melting point. *Journal of the Chemical Society, Faraday Transactions 1: Physical Chemistry in Condensed Phases*, 77(8), 1981–1985. <https://doi.org/10.1039/F19817701981>
- Open Lab, P. (2018, January 18). *Laue Diffraction*. <https://Physicsopenlab.Org/2018/01/18/Laue-Diffraction/>. <https://physicsopenlab.org/2018/01/18/laue-diffraction/>

- Paricio, J., García-Ceballos, S., & Rubio-Navarro, A. (2022). Epistemic Beliefs and Pre-service Teachers' Conceptions of History Instruction. *Frontiers in Education*, 7, 865222. <https://doi.org/10.3389/educ.2022.865222>
- Prasetya Cahya, A., & Surya, W. P. (2025). Model Mental Mahasiswa Pendidikan Kimia Terhadap Konsep Faktor-Faktor Pergeseran Keseimbangan. *Indonesian Journal of Intellectual Publication*, 5(3), 329–341.
- Rahmawati, Y., Zulhipri, Hartanto, O., Falani, I., & Iriyadi, D. (2022). Students' Conceptual Understanding in Chemistry Learning Using PHET Interactive Simulations. *Journal of Technology and Science Education*, 12(2), 303–326. <https://doi.org/10.3926/jotse.1597>
- Rauber, D., Philippi, F., Seibert, J., Huwer, J., Natter, H., & Hempelmann, R. (2019). From Current Science to School – the Facets of Green Chemistry on the Example of Ionic Liquids. *World Journal of Chemical Education*, 7(2), 153–165. <https://doi.org/10.12691/wjce-7-2-15>
- Riley, K. E., & Dutta, S. (2024). Experiences with an Inquiry-Based Ionic Liquid Module in an Undergraduate Physical Chemistry Laboratory. *Journal of Chemical Education*, 101(5), 2022–2029. <https://doi.org/10.1021/acs.jchemed.3c00871>
- Salsabila, E., Hajizah, M. N., & Sampoerno, P. D. (2025). Efektivitas Desain Didaktis Materi Lingkaran Berbasis Realistic Mathematics Education terhadap Kemampuan Pemahaman Konsep Matematis. *Jurnal Riset Pendidikan Matematika Jakarta*, 7(2), 64–73.
- Sheldon, R. A. (2021). Biocatalysis in ionic liquids: state-of-the-union. *Green Chemistry*, 23(21), 8406–8427. <https://doi.org/10.1039/d1gc03145g>
- Sjöström, J., Eilks, I., & Talanquer, V. (2020a). Didaktik Models in Chemistry Education. *Journal of Chemical Education*, 97(4), 910. <https://doi.org/10.1021/acs.jchemed.9b01034>
- Sjöström, J., Eilks, I., & Talanquer, V. (2020b). Didaktik Models in Chemistry Education. *Journal of Chemical Education*, 97(4), 910–915. <https://doi.org/10.1021/acs.jchemed.9b01034>
- Solikha, A. (2022). Content Of Students' Scientific Research Activity and Main Forms of Research Results. *European Scholar Journal (ESJ)*, 3, 88–92. <https://orcid.org/0000-0002-8508-4519>
- Suryati, S., Adnyana, P. B., Ariawan, I. P., & Wesnawa, I. G. A. (2024). Integrating Constructivist and Inquiry Based Learning in Chemistry Education: A Systematic Review. *Hydrogen: Jurnal Kependidikan Kimia*, 12(5), 1166–1188. <https://doi.org/10.33394/hjkk.v12i5.13571>
- Svendsen, B. (2021). The Nature of Science and Technology in Teacher Education. In *IntechOpen*. [www.intechopen.com](http://www.intechopen.com)
- Tairab, H. H. (2001). *How do Pre-service and In-service Science Teachers View the Nature of Science and Technology ?* 19(2). <https://doi.org/10.1080/0263514012008775>
- Takowa, Y., Tangio, J. S., Thayban, T., Kunusa, W. R., Mohamad, E., & Kimia, J. (2025). Faktor Penyebab Kesulitan Siswa SMA Memahami Keseimbangan Kimia : Literature Review. *Fisika Dan Biologi*, 109–123. <https://doi.org/10.61132/jupenkifb.v1i3.290>
- Tala, S. (2013). The Nature Of Technoscience (NOTS). In M. P. Clough, J. K. Olson, & D. S. Niedeshauser (Eds.), *The Nature of Technology* (pp. 51–84). Sense Publisher.
- Valencia Narbona, M., Núñez Nieto, P., & Cofré Mardones, H. (2023). Understanding of Nature of Science (NOS) in pre-service teachers with different science content knowledge, before and after an intervention. *International Journal of Science Education*, 45(2), 125–143. <https://doi.org/10.1080/09500693.2022.2152294>

- Valente, B., Maurício, P., & Faria, C. (2022). The Influence of Real-Context Scientific Activities on Preservice Elementary Teachers' Thinking and Practice of Nature of Science and Scientific Inquiry. *Science & Education*, 33(1), 1. <https://doi.org/10.1007/S11191-022-00377-5>
- Venessa, D. M., Hernani, H., & Halimatul, H. S. (2019). Exploring View of Nature of Science and Technology Pre-Service Chemistry Teachers. *Journal of Science Learning*, 3(1), 19–28. <https://doi.org/10.17509/jsl.v3i1.17757>
- Venessa, D. M., Hernani, & Halimatul, H. S. (2020). Pre-service chemistry teachers' learning obstacles in understanding the relationship between the chemical structures and physicochemical properties of ionic liquids. *Journal of Physics: Conference Series*, 1521(4). <https://doi.org/10.1088/1742-6596/1521/4/042065>
- Wang, M., Gao, S., Gui, W., Ye, J., & Mi, S. (2022). Investigation of Pre-service Teachers' Conceptions of the Nature of Science Based on the LDA Model. *Science and Education*, 32(3), 589–615. <https://doi.org/10.1007/s11191-022-00332-4>
- Wang, R., Fang, C., Yang, L., Li, K., Zhu, K., Liu, G., & Chen, J. (2022). The Novel Ionic Liquid and Its Related Self-Assembly in the Areas of Energy Storage and Conversion. *Small Science*, 2(9), 2200048. <https://doi.org/10.1002/smsc.202200048>
- Wong, S. L., Wan, Z., & Cheng, M. M. W. (2011). Learning Nature of Science Through Socioscientific Issues. *Socio-Scientific Issues in the Classroom*, 39, 245. [https://doi.org/10.1007/978-94-007-1159-4\\_14](https://doi.org/10.1007/978-94-007-1159-4_14)
- Yeboah, J., Metott, Z. J., Butch, C. M., Hillesheim, P. C., & Mirjafari, A. (2024). Are nature's strategies the solutions to the rational design of low-melting, lipophilic ionic liquids? *Chemical Communications*, 60(29), 3891–3909. <https://doi.org/10.1039/d3cc06066g>
- Yeşiloğlu, S. N., & Köseoğlu, F. (2020). Epistemological problems underlying pre-service chemistry teachers' aims to use practical work in school science. *Chemistry Education Research and Practice*, 21(1), 154–167. <https://doi.org/10.1039/c8rp00212f>
- Yusra, R. A., Kusumah, F. H., & Suryadi, A. (2025). The Effect of PjBL-STEM on Enhancing Critical Thinking Skills in Renewable Energy Topics to Support Quality Education. *Jurnal Pendidikan Matematika Dan Sains*, 13, 26–37. [https://doi.org/10.21831/jpms.v13iSpecial\\_issue.86537](https://doi.org/10.21831/jpms.v13iSpecial_issue.86537)
- Zhang, G., Li, Y., Zhou, G., & Ho, S. W. Y. (2022). Exploring Pre-service Science Teachers' Perspectives on the Nature of Science: A Comparative Study Between China and Canada. *ECNU Review of Education*, 5(3), 520–536. <https://doi.org/10.1177/2096531120966782>