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# Pre-Service Chemistry Teachers' Preconceptions about Rare Earth Coordination Chemistry: Results from an Explorative Interview Study

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**Abstract:** This research aims to identify students' preconceptions about rare earth coordination chemistry. The method used in this research is exploratory interviews. This research involved 25 pre-service chemistry teacher at a university in West Java Province, Indonesia. The collected data was analyzed using qualitative content analysis. The research results showed that 60% of students were able to identify electronic waste as a source of valuable metals, but others did not know that there were rare earth metals contained in it. As many as 32% know ionic liquids as environmentally friendly solvents, but the majority of students do not understand the physicochemical properties of ionic liquids and the interactions between ionic liquids and rare earth metals. As many as 8% of students were able to explain the reaction to form rare earth metal coordination compounds correctly, while only 4% were able to explain the concept of luminescence in these compounds. These findings indicate the need for coordination chemistry course design that accommodates students' learning needs and links them to relevant environmental contexts to improve students' understanding and systems thinking skills.

**Keywords:** Explorative interview; Preconceptions; Rare earth coordination chemistry; Systems thinking

## Introduction

Pre-service chemistry teachers' preconceptions are described as "learners' internal representations constructed by others such as teachers, textbooks, articles" (Neumann & Hopf, 2012; Treagust & Duit, 2008). Preconceptions have an important role as a basis for building further student knowledge (Morrison & Lederman, 2003). However, in fact, there are still many student conception construction processes that are not always in line with scientific conceptions. Mistakes in student conceptions can give rise to misconceptions and learning difficulties (Rahmadani et al., 2023; Rokhim et al., 2023). Misconceptions can occur when students' conceptions do not match scientific conceptions. However, on the other hand, misconceptions can be used as improvements in the learning process as part of conceptual change (Damsi & Suyanto, 2023; Lewis et al., 2021; Raabi & Musta, 2022). Educators should pay attention to symptoms of misconceptions and be able to anticipate so that students' preconceptions can approach scientific conceptions. Identifying and understanding student preconceptions before learning can be a strategy in developing effective learning designs (Suparwati, 2022).

Although there have been many publications regarding student preconceptions, in general it is very rare for student preconception research to be carried out

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on rare earth metal coordination complex compound materials. Most of the research focuses on students' preconceptions regarding the chemistry of main group elements, rare earth elements, chemical bonds, reduction and oxidation and other basic chemistry topics. A study regarding preconceptions on chemistry topics was conducted by Wijaya et al. (2020) in one of the middle schools in Indonesia, as many as 76% of students' preconceptions were in the "low understanding" category in the context of artificial muscle in the application of chemistry learning in high schools. A study conducted by Demİrcİ et al. (2004), the results of preconceptions regarding the topic of electricity and magnetism, can investigate the misconceptions experienced by students and at the same time can develop designs for new learning activities on this topic. Research in teacher education and science education (Clement, 1993; Morrison & Lederman, 2003) has demonstrated the influence of students' preconceptions on their learning experiences and related outcomes. Students' preconceptions about the learning process may be a barrier and impetus to their learning experience and that identifying and understanding these preconceptions can help in creating an effective learning process. A study conducted by Niebert et al. (2013) revealed that analyzing students' prior knowledge and scientific conceptions was proven to produce good learning designs.

Studying material on rare earth coordination complex compounds is very necessary for students' preconceptions. The concept of this material becomes part of life experience because students are often faced with the term rare earth metals as applied to electronic waste. Rare earth metals can be applied both in the form of elements and complex compounds. Media reports about valuable minerals for the future in the form of rare earth metals, as well as ongoing discussions about global demand trends related to rare earth metals and their complexes in industrial progress, all of these issues include the terms rare earth metals and their complex compounds in various contexts. Therefore, students' preconceptions need to be identified to design lectures on rare earth coordination complex compounds which are closely related to environmental, social and sustainability contexts (Solihah et al., 2024; Utami et al., 2023; Zulkarnaen et al., 2023).

At the educational level, rare earth metals are one of the topics in discussing chemical elements (Pinasti et al., 2022). The rare earth metals taught in undergraduate chemistry education do not come from mining but from the recovery of electronic waste. However, most curricula in schools and universities do not provide accurate scientific explanations about the characteristics of rare earth metals, sources of abundance in nature, sources of abundance in industrial waste products, recovery methods and interactions that occur with these elements in solvents, used when separating. So it is important to include the topic of rare earth metals in school and college curricula.

Rare earth metals are important minerals in today's environmentally friendly energy development and energy conservation. Significantly, the presence of rare earth metals can contribute to the improvement of modern technology such as fluorescent lamps, magnets, cell phones, computers, rechargeable batteries and other electronic equipment (Klinger, 2018). From a geopolitical perspective, rare earth metals are a complex discussion including the source of their existence, the recovery process from waste, the use of environmentally friendly solvents and sustainability aspects (Klinger, 2018; Powell, 1964). This is what makes the discussion of rare earth metals diverse and can be used to add context to learning. Context learning really helps students to overcome problems regarding chemical concepts that are abstract and considered irrelevant to everyday life (Pernaa et al., 2022).

To achieve the desired knowledge about rare earth coordination complex compounds as future materials, sustainable molecular thinking is needed. This requires systems thinking skills to study the composition and properties of materials at the molecular level and predict sustainability aspects. Systems thinking equips students to recognize the interconnection between chemistry content and various contexts that develop in society. Students should be given the opportunity to use systems thinking to integrate what they have learned in class with chemistry-related issues that occur in society (Diah Murti & Hernani, 2023).

Systems thinking at the molecular level can be implemented on the topic of rare earth coordination complex compounds on a massive scale at the school level. Competencies achieved in this thinking skill can provide students with an emphasis on concepts and practice in studying the properties, synthesis and applications of rare earth coordination complex compounds. Strengthening systems thinking skills, providing the ability to link the reconstruction of the chemical content of rare earth coordination complexes with the principles of sustainability at the molecular level. Systems thinking has been proven to increase students' understanding and be able to relate the learning context to chemistry content and sustainable chemistry education, sustainable chemistry education in this case thinking at the molecular level (Mahaffy et al., 2019), helping to develop dynamic thinking (Kisworo et al., 2021), as well as contributing to social and technological environmental aspects (Orgill et al., 2019). Besides the learning experience, systems thinking plays an important role in constructing students' conceptions at the molecular level of rare easrth coordination complex compounds. The results of this student preconception research can be used as a basis for developing a learning design for the coordination complex chemistry of rare earth metals.

This research presents novelty in the form of rare earth metal coordination chemistry topics identified from student preconceptions. This research is important to conduct because the topic is based on students' preconceptions and knowledge needs. Identifying and understanding student preconceptions helps educators design more effective and relevant learning, as well as connecting chemistry material to real-life contexts, such as the application of rare earth metals in modern technology. The topic of rare earth metals often receives little attention in chemistry curricula. This research can reveal the need to include material about rare earth metals more comprehensively in the curriculum, from their properties and sources to their applications in modern technology and sustainability issues.

## Method

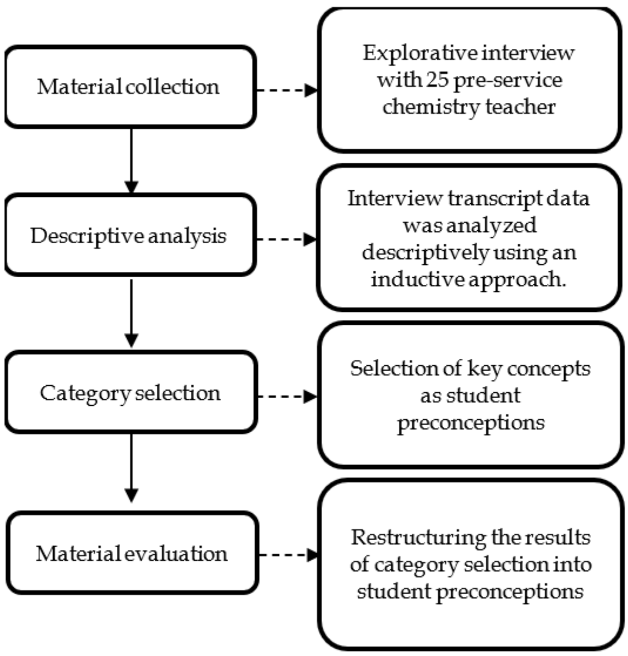


**Figure 1.** Stages of qualitative content analysis (Mayring, 2022)

The technique for collecting data on student preconceptions was carried out using exploratory interviews. The instrument prepared is an interview question guide. The respondents were 25 prospective chemistry teacher students at a university in West Java, Indonesia. The interview lasted approximately 45-60 minutes, following an interview guide consisting of 18 open-ended questions. Interviews were recorded and partially transcribed and analyzed quantitatively and qualitatively according to the type of question. Qualitative results were obtained through qualitative analysis of interview content which was transcribed following procedures (Mayring, 2022). Student answer categories can be divided into several scores, where score 2 is for answers from students who know the concept and can provide answers in accordance with the scientist's conception. A score of 1 if the student answered incorrectly, or had a misconception and a score of 0 if the student did not know, answered incorrectly or deviated far from the concept being asked. Figure 1 shows the steps in analyzing the results of exploratory interviews to obtain student preconceptions using the qualitative content analysis method.

## Results and Discussion

*Pre-service Chemistry Teachers' Preconceptions about Rare Earth Metals, Coordination Complex Compounds and the Context Related to Metal Content in Electronic Waste*

Figure 2 shows the percentage of answers of pre-service chemistry teacher to questions number 1 to. 6. The first category, contains 6 questions asked to explore pre-service chemistry teacher initial knowledge about the context related to the chemical content of rare earth metal coordination complexes and the relationship between the two. Figure 2 shows the percentage of answers of prospective chemistry teacher students to questions number 1 to number 6.

Analysis of the opening question about electronic waste revealed that most students observed and knew about electronic waste around where they lived. Students understand that this waste has a negative impact on the environment, on the other hand, they think that electronic waste contains valuable chemical elements. As many as 60% of respondents were able to explain electronic waste and mentioned words related to the category "valuable chemical elements or potential metals". This conception is in accordance with the scientific conception. According to scientists' conception, electronic waste is consumable electronic objects that contain dangerous elements that can have a negative impact on the environment and human health (Nnorom & Osibanjo, 2008; Sinaga et al., 2023). Besides having a negative impact, electronic waste contains transition metals as well as very valuable rare earth metals. A total of 28% of respondents experienced misconceptions about electronic waste. They define electronic waste as electronic products that are truly no longer useful and must be thrown away. 12% of respondents have never studied or are indifferent to the term electronic waste. Therefore, this student conception is different from the scientific conception. It can be concluded that the majority of respondents were able to explain electronic waste related to environmental issues. This is because students have studied material related to environmental issues in environmental chemistry courses.

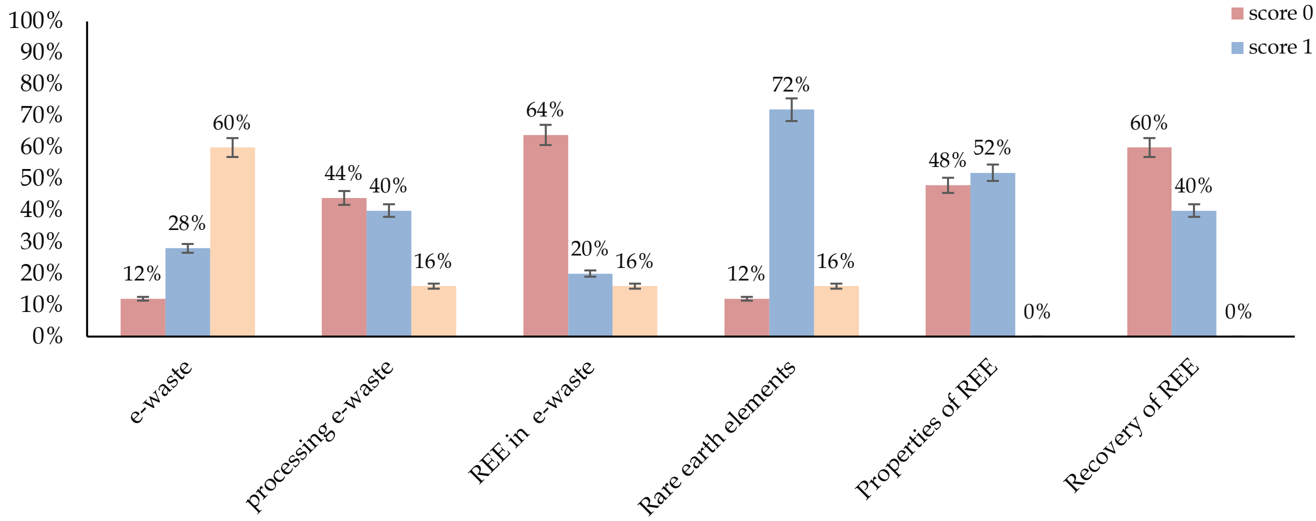


**Figure 2.** Percentage of answers for questions number 1 until 6

**Table 1.** Question from Interviewers Guiden and Grouping of Student Answer Score Results

| Questions | Number of students who answered each score | | |
|---|---|---|---|
| | 2 | 1 | 0 |
| What information did you get from the discourse presented? | 15 | 7 | 3 |
| Do you have ideas for overcoming the electronic waste problem in Indonesia? | 4 | 10 | 11 |
| Can you explain why tube TVs can display colors and images? | 4 | 5 | 16 |
| What can you explain regarding the elements in the lanthanide group along with Sc and Y elements? | 4 | 18 | 3 |
| Give your explanation of the meaning of the table which shows the relationship between Currie temperature and the magnetic properties of rare earth elements? | 0 | 13 | 12 |
| Give your idea a suitable recovery method for recovering rare earth metals from electronic waste components? Explain the reasons why the separation method you have chosen is suitable for separating REEs from the mixture! | 0 | 10 | 15 |
| Can you explain about deep eutectic solvents (DESs)? | 8 | 6 | 11 |
| Deep Uetectic Solvents (DES) are an alternative to common solvents. What do you know about DES from their chemical properties and physical properties? | 0 | 13 | 12 |
| DES has a carboxylate group, if used as an extractant in the separation of rare earth elements, a complexing reaction occurs which forms rare earth metal coordination complex compounds. Can you explain the reaction mechanism! | 0 | 2 | 23 |
| Can you explain what causes REE complexes to have such large coordination numbers? | 2 | 7 | 16 |
| Have you ever studied coordination complex compounds? | 4 | 3 | 18 |
| Have you ever studied about rare earth metal coordination complex compounds! Can you explain it! | 0 | 7 | 18 |
| Coordination complex chemical compounds of rare earth metals have paramagnetic and ferromagnetic properties. How can you explain the magnetic properties of this complex? | 4 | 5 | 16 |
| Can you explain why in the crystal structure of rare earth metal coordination complexes can form several regular geometries? | 0 | 3 | 22 |
| What do you know about luminescence properties? And provide an explanation of why rare earth metal coordination complex compounds can have luminescence properties! | 1 | 4 | 20 |
| Give examples of the uses of rare earth metal complex compounds based on their chemical and physical properties! | 4 | 9 | 12 |
| Rare earth metals and the synthesis of rare earth metal coordination complex compounds have great benefits in the world of trade. This will affect the country's economic sector. How can you explain this connection? | 9 | 5 | 11 |
| In your opinion, what are the benefits of studying rare earth metal coordination complex compounds from electronic waste recovery in chemistry learning? | 8 | 12 | 5 |

When asked about solutions to dealing with electronic waste in the second question, the results were quite clear that the majority of students (44%) did not know about how to deal with electronic waste. Most students said it was buried in a place far from residential areas. Some other respondents (40%) experienced misconceptions regarding how to deal with or process electronic waste. Respondents thought that electronic waste could only be destroyed and could not be used again. A small portion of student respondents (16%) were able to explain environmentally friendly recycling methods to deal with electronic waste. This conception is in accordance with the scientific conception, that. According to scientists' conception, electronic waste can be recycled to obtain products that can be reused. The scientific recycling process is carried out on a molecular scale through the recovery of valuable metals (Briefs & Earth, 2016; Kisworo et al., 2023).

When asked to explain that a CRT (chatode ray tube) TV can display colors and images, the majority of students (64%) could not explain the relationship between the elements that play a role in the TV. Some students (20%) could explain that TVs are coated with certain elements that can emit light and images. A small portion (16%) of students were able to explain the role of rare earth elements in TVs that adapt CRT technology to display color and light.

In the fourth question, students were asked to explain the elements found in the Lanthanide group plus the elements Sc and Y. Most students (72%) experienced misconceptions in answering, they mentioned "non-main group elements, as well as metals that are rarely found in nature." This concept is not in accordance with scientific concepts. The reason students experience misconceptions is because they do not have an adequate understanding of rare earth elements which consist of the lanthanide group plus the elements Sc and Y. A small number of students (12%) did not answer or did not know. Only 16% of students answered correctly "lanthanide elements, rare earth elements". This conception is in accordance with the scientific conception. According to scientists' conception, the lanthanide group plus the elements Sc and Y are known as rare earth metals. Rare earth metals are not as "rare" as their name suggests. The number of rare earth metal deposits is limited, but the abundance of the elements is quite large.

The interviewer showed the students a table relating the magnetic properties of rare earth elements. they were asked to explain the meaning of the table. Not a single respondent could explain that rare earth elements have paramagnetic properties and only gadolinium has ferromagnetic properties. 52% of respondents only stated that rare earth elements have paramagnetic properties while 48% of respondents misunderstood the information shown by the interviewer. Most students answered incorrectly and answered incorrectly because they did not have an adequate understanding of the magnetic properties of rare earth metals.

Question number 6 is related to methods for recovering metal from electronic waste in the form of solid samples. As many as 60% of respondents did not know the method for separating metals from their mixtures. As many as 40% of respondents answered incorrectly. Respondents already knew that in removing metals from mixtures, the types of methods mentioned by students were not appropriate, for example filtration, chromatography. Not a single student could explain the method for recovering metal from electronic waste from a solid mixture through extraction or leaching (Kisworo et al., 2023; Suganal et al., 2018; Trinopiawan et al., 2016; Yudha et al., 2022).

The second category, regarding the importance of studying the topic of environmentally friendly solvents or extractants (green chemistry). Figure 3 shows the percentage of answers of prospective chemistry teacher students to questions number 7 to 9.

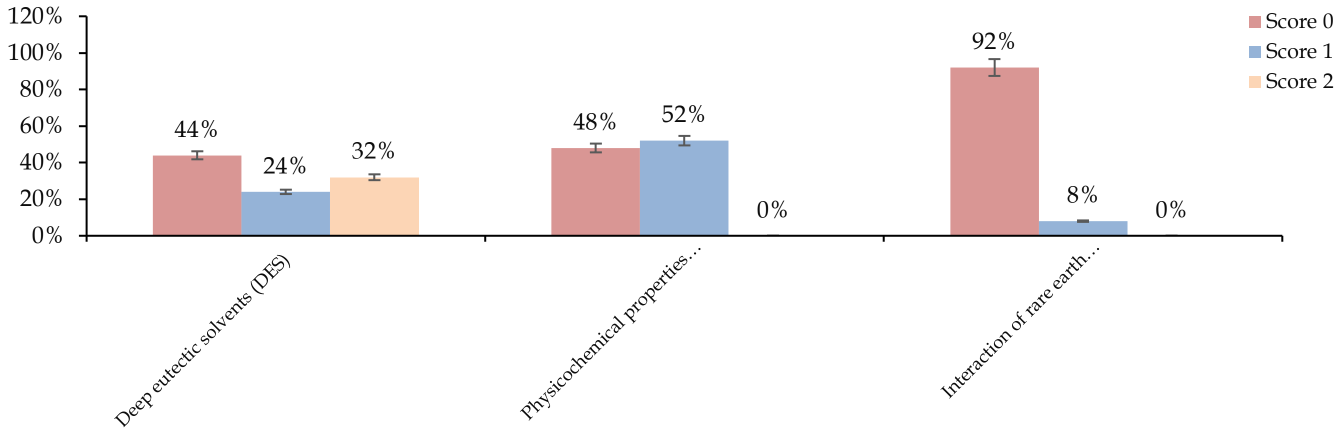


**Figure 3.** Percentage of answers for Questions number 7 until 9

When asked about the solvent content used in the extraction process, the result was that most students (44%) of respondents did not know the correct solvent in the extraction process. Most students have difficulty answering this question because students do not have sufficient basic knowledge about green chemistry-based extractants. A small percentage of students (24%) answered that they used common solvents that had a negative impact on the environment, students said, for example, strong acids, strong bases and organic compounds. As many as 32% of students said that ionic liquids are environmentally friendly solvents and have quite wide miscibility. This conception is in accordance with the scientific concept, ionic liquids as solvents have high thermal stability, low melting point and are not flammable. This is what makes ionic liquids an environmentally friendly solvent (Agung et al., 2023).

Question number 8 concerns the properties and advantages of deep eutectic solvents (DES). To explore initial knowledge, respondents were asked questions about the differences between general solvents and DES solvents. The result was that none of the respondents could correctly differentiate between the two solvents. As many as 52% of respondents could only explain general solvents such as strong acids, strong bases and organic compounds. However, respondents did not know about deep eutectic solvents, both in terms of their properties and advantages. As many as 48% of respondents gave wrong answers or did not know the difference between solvents in general and DES solvents. Respondents who gave wrong answers assumed that the DES solvent was applied to limited solutes.

Question number 9 concerns the reaction mechanism that works as a solvent. As many as 92% of respondents did not know the reaction mechanism that occurred between DES and the sample in separating the metal from the mixture. As many as 8% of respondents knew that DES was able to bind metals from the mixture, but did not know the type of chemical bond formed between the metal and DES. None of the respondents knew the exact reaction mechanism between DES and the metal in the mixture (Adhitya et al., 2023; Milenia et al., 2021). This shows that most of the conceptions expressed by students are not in accordance with scientific concepts. Most students have difficulty writing reactions between rare earth metals and solvents as ligands, this is because students do not have an adequate understanding of the interactions that occur between metals and ligands in forming coordination complex compounds.

The fourth category, regarding the importance of studying the reaction of the formation of coordination complex compounds between leached rare earth metals and carboxylic group ligands as DESs. Figure 4 shows the percentage of answers of prospective chemistry teacher students to questions number 10 to 14.

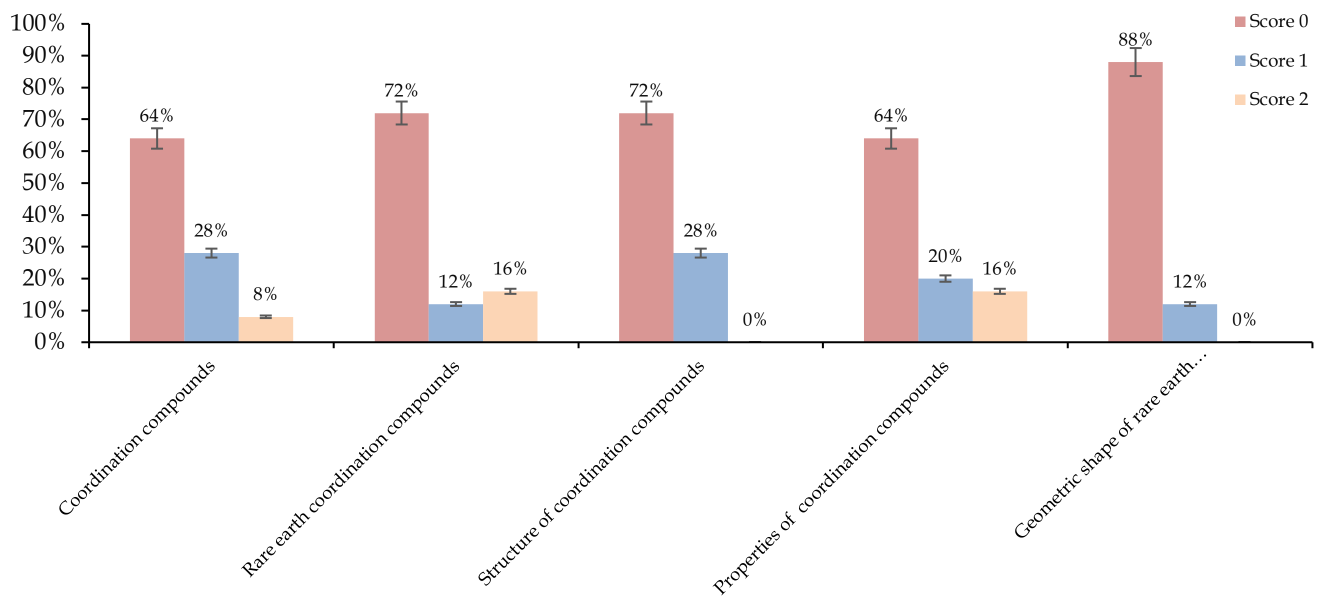


**Figure 4.** Percentage of answers for questions number 10 until 14

Many students (64%) were unable to explain the difference between transition metal coordination complex compounds and rare earth metal coordination complex compounds. This difficulty is caused by not having received teaching material about the chemistry of rare earth metal elements and their complex compounds. As many as 28% of respondents could only explain each coordination complex compound from the aspect of the central atom, and there was a misconception that rare earth metals were only in the lanthanide group but did not include the additional 2 elements scandium (Sc) and yttrium (Y). Where transition metal coordination complex compounds have a central metal from a transition metal, while rare earth metal coordination complex compounds have a central metal originating from lanthanide group metals. However, in further explanation the respondents were not precise in distinguishing the coordination number between transition metal coordination complex compounds and rare earth metal coordination complex compounds. Respondents explained that the two complex compounds have the same coordination number. Only a small percentage (8%) of students can explain the reaction to form rare earth metal coordination complex compounds correctly. This conception is in accordance with scientific concepts.

When faced with questions regarding the formation of coordination complex compounds, all students stated that they had studied coordination complex chemistry. Students are shown several pictures of orbital diagrams of valence bond theory (VBT), crystal field theory (CFT), and molecular orbital theory (MOT). Only 16% of students answered correctly the formation of coordination complex compounds by writing down the mechanism for bond formation between the central metal and the ligand. A small number of students (12%) answered incorrectly regarding the formation of coordination complex compounds based on VBT, CFT and MOT. Most students (72%) answered with a wrong explanation of the concept. The reason most students have difficulty answering this question is because students have never studied the chemistry of rare earth coordination complexes before

When shown a picture of the chemical structure of the rare earth metal coordination complex, the result was that none of the respondents could explain the chemical structure of the coordination complex with the central atom of the rare earth metal. As many as 28% of respondents answered incorrectly, the picture shows a coordination complex compound consisting of a central atom and a ligand. Students did not provide a specific explanation regarding the central atom in the form of rare earth metals. Most students (72%) answered incorrectly, there was a misconception that the Sc and Y elements were mentioned as ligands.

Questions regarding the magnetic properties of rare earth metal coordination complex compounds were addressed to students. A small number of students (16%) were able to analyze that rare earth metal coordination complex compounds have a magnetic field. Students can explain the magnetic properties by describing the unpaired electrons in the orbitals of rare earth metals. Students explain that the presence of unpaired electrons shows the magnetic properties of coordination complex compounds. As many as 20% of students answered incorrectly. Students answered that magnetic properties arise because of the central atom in the form of a metal which does have a magnetic field from the ground state. Most of the students (64%) could not answer or completely misunderstood the concept. Most students were unable to answer because they did not have an adequate understanding of the properties of rare earth metals and the properties of their complex compounds.

A small number of students (12%) answered that they did not correctly explain the geometric shape of rare earth metal coordination complex compounds. This difficulty is because there are geometric shapes that are considered "new" by students, whereas geometric shapes that are similar to transition metal coordination complex compounds generally respond correctly, for example for ligand six students can say that the geometric shape is octahedral. Meanwhile, 88% of students answered incorrectly and not a single respondent answered correctly.

The fourth category, regarding the importance of sustainable urban mining as a study of the complex chemistry of coordination. Figure 5 shows the percentage of answers of prospective chemistry teacher students to questions number 15 to 18.

Question number 15 concerns the typical properties of rare earth metal coordination complex compounds that have luminescence properties. To explore initial knowledge, students are asked questions about the phenomenon of photoluminescence. Based on the results of the interview, a small number of students (4%) were able to answer correctly that luminescence is the property of luminescence. Furthermore, the respondents explained that rare earth metal coordination complex compounds have luminescence properties because these complex compounds have a high energy level and are abundant in the 4f configuration thus allowing the transfer of electrons in orbitals (excitation) accompanied by the emission of light energy. As many as 16% of students had heard of photoluminescence as a substance that glows light, but respondents could not explain why an element can give rise to luminescence properties. Most students (80%) are not aware of photoluminescence. Most of the students who answered incorrectly were because they did not understand the Jablonski diagram which explains the absorbance, fluorescence and phosphorescence factors.

When questions regarding applications were based on chemical and physical properties, a small percentage of students (16%) could answer correctly. Students can mention the applications of rare earth metal coordination complex compounds based on their photoluminescence and magnetic properties. Utilizing the photoluminescence properties of this complex compound can be applied to components for making electronic goods such as televisions, cellphones, LED lights. Meanwhile, the use of magnetic properties is applied as a strong magnet which is needed as a material in earphone components, hard disks and others. the use of chemical properties applied as a catalyst. Another portion (36%) of students were able to mention the application of rare earth metal coordination complex compounds based on their magnetic properties. The respondent explained that the central atom in the form of a rare earth metal has strong magnetic properties, therefore in the state of a coordination complex compound it still has strong magnetic properties. However, students did not mention the application of chemical properties. Most students (48%) did not know the applications of rare earth metal coordination complex compounds.

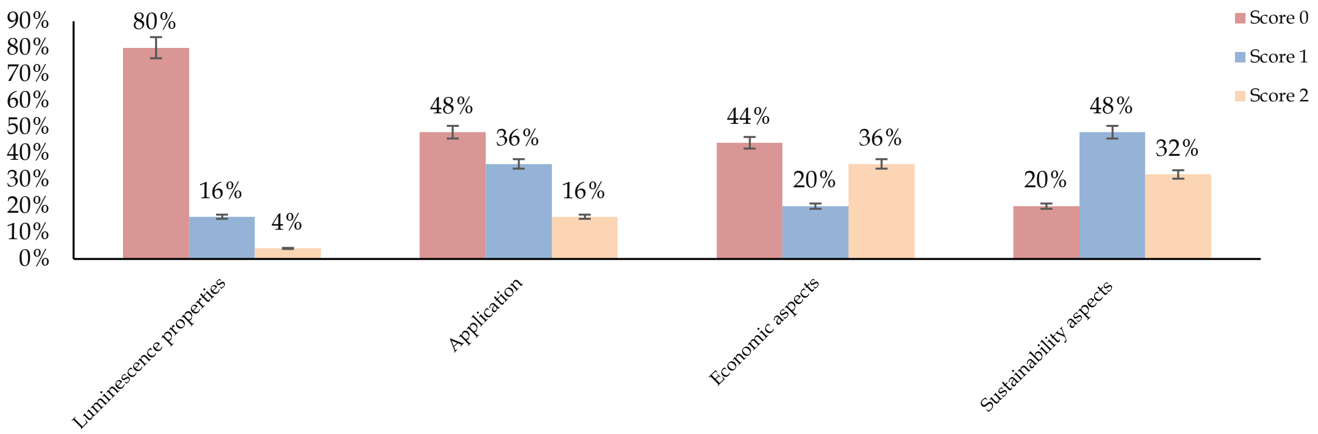


**Figure 5.** Percentage of answers for questions 15 until 18

The question regarding the relevance of the synthesis of rare earth metal coordination complex compounds to the economic sector is faced by students. As many as 44% of students could not answer or did not know. Meanwhile, 20% of students know that the production of rare earth metal coordination complex compounds can influence the industrial world, but they cannot explain the relationship. as many as 36% of students answered correctly, they already know that the production process aims to meet needs in the industrial world, the defense industry, the medical industry which will have an impact on a country's economic growth. students stated that developed countries are competing to produce goods based on earth jaran metal, because demand for products on the international market is increasing, which will improve a country's economy.

The majority of students (48%) answered about the benefits of studying rare earth metal coordination complex compounds from electronic waste recovery. However, they have not provided a scientific reason for the benefits they mention. Students only give general answers, such as being beneficial for the environment, for the economy, for technology without providing explanations in scientific concepts. A small portion of students (20%) could not answer or did not know. The majority (32%) of students were able to explain that studying rare earth metal coordination complex compounds from electronic waste has enormous benefits. They were able to explain that the formation of rare earth metal coordination complex compounds from the re-collection of electronic waste would reduce the increase in the volume of electronic waste from year to year. Respondents were able to think analytically and predictively that overcoming the problem of electronic waste which is part of problems related to environmental issues is one of the efforts to save the earth as a place for living creatures to live and maintain its sustainability in a sustainable manner.

*The Importance of Systems Thinking in Directing Pre-Service Chemistry Teachers' Preconceptions into Learning the Complex Chemistry Context of Rare Earth Metal Coordination*

Based on the results of exploratory interviews, most students experienced misconceptions or learning difficulties in studying the molecular structure of rare earth metal coordination complex compounds. It can be identified that learning chemistry of rare earth metal coordination complexes only teaches chemical content without linking learning in context. Learning presents complex and abstract concepts, without practicing thinking skills in connecting material content with case studies that occur in real life (Noris et al., 2024). Meaningful learning is learning that can provide benefits for real life by considering both social, environmental and economic aspects (Santoyo-Castelazo & Azapagic, 2014; Kisworo et al., 2021) .

Therefore, student learning design can start contextually and then move on to the complex chemistry content of rare earth metal coordination (Jegstad & Sinnes, 2015). Learning design can be designed by developing skills that are relevant to contextual issues or problems. Of course, a systems thinking framework is very necessary to connect the two. By strengthening systems thinking, students can construct relationships between molecular components such as the synthesis of complex coordination compounds, bonds between the central metal and ligands, and their applications. The overall results of the interview can be compiled into a learning design as shown in Figure 6.

Figure 6 explains how systems thinking can relate content, context, and student involvement in creating a chemistry learning design (Salsabila et al., 2024). Content knowledge has an important role as the basis of a learning program, because this model comes from existing chemistry subjects. However, content knowledge is also important for students to understand socio-scientific issues, such as e-waste (Hodson, 2013; Utami et al., 2023). Learning must also pay attention to sustainability aspects in chemistry education, for example synthesizing green chemistry-based solvents. Context learning can be done with field work, this is an important part of connecting chemistry content (Jusniar et al., 2023; Latifah, 2021; Sari & Atun, 2023; Witri et al., 2023).

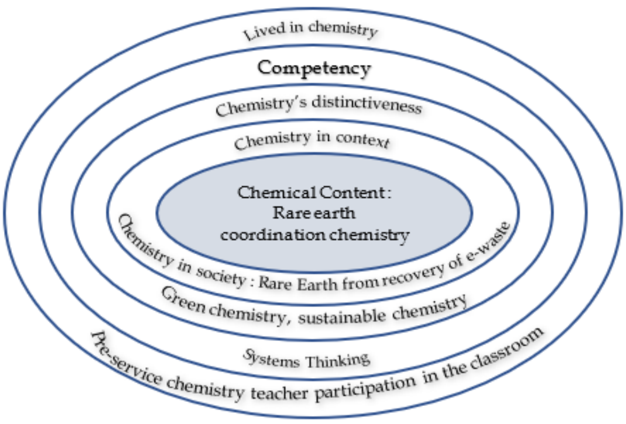


**Figure 6.** Learning design rare earth cordination chemistry based on pre-service chemistry teachers' preconceptions

Students must engage in systems thinking in understanding that electrons have an important role in coordinating bonds in forming complex structures. This helps students understand the basic concepts of bond theory and strengthens their understanding of the process of forming coordination bonds. Students' preconceptions also indicate that they have not yet focused on the physical and chemical properties of rare earth metal coordination complex compounds. Systems thinking helps students relate molecular structure to these properties, as well as understand the relationship between the coordination complex chemistry of rare earth metals and other theories such as valence bond theory, crystal field theory, or molecular orbital theory. This helps students relate the concepts they learn to a larger conceptual framework. By strengthening systems thinking, students can overcome student preconceptions and develop a deeper understanding of the complex coordination chemistry of rare earth metals, enabling them to connect these concepts in a broader, integrated system (Kisworo et al., 2023).

## Conclusion

In general, pre-service chemistry teachers' preconceptions show that the topic of coordination chemistry of rare earth metals has never been studied before by students. Based on pre-conception analysis, it shows that students have learning difficulties in understanding chemical content related to coordination chemistry of rare earth metals. Learning difficulties in this content have an impact on low understanding in understanding the content of rare earth metal coordination chemistry. Therefore, it can be concluded that pre-service chemistry teachers' preconceptions regarding rare earth elements, rare earth metal recovery methods, solvent properties of deep eutectic solvents, structure and geometric shape of rare earth metal coordination compound, special properties in the form of luminescence properties of rare earth metal coordination complex compounds can be developed into a chemistry content structure, especially in constructing learning designs in coordination chemistry lectures.

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**Author Contribution**
Conceptualization, B.K., and A.M.; methodology, B.K., A.M., and L.; validation, A.P.; formal analysis, B.K., and A.M.; investigation, B.K.; resources, B.K.; data curation, B.K., A.M., L., and A.P.; writing—original draft preparation, B.K.; writing—review and editing, A.M., L., and A.P.; supervision, A.M. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest**
The authors declare there is no conflict of interest.

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