Designing Research Based-Teaching Learning Sequence about Chemistry of the Elements and Sustainable Metallurgy: An Effort to Strengthen Students Systems Thinking Skills

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Abstract. Sustainable nickel laterite metallurgy can be introduced as a scientific issue through structured learning steps. This study aims to develop a validated and tested learning design that can foster system thinking among prospective chemistry teachers using a research-based approach in the context of sustainable nickel laterite metallurgy. The Development Research process guided by the Model of Educational Reconstruction (MER) consists of three main components: (1) clarification and analysis of science content, (2) research on students' preconceptions regarding specific science content, and (3) design and evaluation of the learning stages and learning environment. The research subjects involved 60 students from the chemistry education program taking the element chemistry course at a public university in Bandung and Bandar Lampung. Data collection was carried out using instruments for the learning design developed based on scientific conceptions, preconceptions, and system thinking, as well as triangulation among evaluators regarding the learning design and student response questionnaires concerning the element chemistry course, along with interviews about the course. The chemistry education curriculum can consider using a research-based learning design that incorporates sustainability aspects into chemistry practices to enhance students' system thinking skills.

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1 Introduction

The topic of ‘‘sustainable metallurgy of laterite nickel’’ has become one of the main issues in mining and metallurgy research and development worldwide. As demand for nickel increases, particularly for battery production and other sustainable technologies, attention to the environmental impact of laterite nickel processing has also grown. However, despite the increasing discussion of this issue in public, political, and scientific spheres, the integration of this topic into educational curricula, especially in chemistry education programs, has not been widely implemented. In science teaching, educating students about sustainable metallurgical processes and their environmental impacts can raise their awareness of the global challenges faced by the industry. As an effort to introduce sustainable laterite nickel metallurgy into the learning process, a series of instructional design stages has been developed. This design aims to introduce students to nickel extraction processes from both primary and secondary sources using more environmentally friendly methods. This can be achieved by linking nickel contextually with the content on Eutectic Ionic Liquids (EILs) as environmentally friendly solvents [1]. Furthermore, students will also be encouraged to explore how waste generated from nickel processing can be minimized using this technology during the learning stages they will undertake.

Teaching Learning Sequences (TLS) can be studied and understood through various approaches. TLS as a method for organizing teaching activities [2]. TLS is a learning cycle based on research outcomes [3]. TLS as an activity and product of intervention research [4]. In general, TLS reflects the close relationship between the teaching and learning processes. The learning stages encompass teaching activities that have been thoroughly researched and tailored to students’ needs based on empirical evidence [5]. A key characteristic of TLS is the effort to connect scientific views with the learners [4].

A framework that can be used to develop the design of TLS for integrating science and technology from a content knowledge perspective is the Model of Educational Reconstruction (MER) [6]. MER is a suitable framework for identifying key ideas in science and natural phenomena that are utilized by technological devices or processes. From an epistemological standpoint, educational reconstruction is based on a constructivist approach, where learning is understood as independently constructing scientific knowledge through existing ideas, experiences, concepts, and understandings [7].

In the context of laterite nickel sustainability, the importance of designing TLS within the chemistry education curriculum is becoming increasingly relevant. Given that the laterite nickel extraction process has significant environmental impacts, well-designed learning experiences can help students understand the scientific concepts underlying extraction technologies while emphasizing the importance of sustainable solutions. By using the MER framework, the curriculum can be structured to integrate scientific and technological aspects, encouraging students to connect these aspects with the environmental, social, and economic impacts of each learning step. This TLS design aims to prepare students to play a role in finding innovative solutions to global challenges related to sustainability.

In the context of education, Mahaffy describes systems thinking as a way to see how chemical components are interconnected within a broader context, including social, economic, and environmental aspects.[8] This approach helps students understand the complexities of the real world, including the sustainability challenges faced, and encourages them to consider the long-term impacts of actions and decisions made in the fields of chemistry and science in general. Thus, systems thinking invites students to think holistically, enabling them to apply their chemistry knowledge in a larger context and understand how science can contribute to solving global issues. Success in integrating sustainability into chemistry practice is a crucial role for chemistry education to better equip students to address the sustainability of the Earth [8].

2 Method

The method used is Development Research, combined with the MER [6]. The first stage involves analyzing, clarifying, and reconstructing the structure of scientific content (scientific explanation) into a structure that is suitable for teaching (pedagogical explanation). The results of the analysis, clarification, and reconstruction in the first stage will serve as the foundation for the second stage, which involves designing the TLS The next stage is an analytical study related to students' preconceptions about the reconstructed topic. In this second stage, students' preconception studies will be used as a reference for developing the TLS design.

In the final stage, the teaching and learning process will be implemented using the developed design, which reflects the outcomes of the implementation for further improvement through trials. These trials will involve 60 chemistry education students enrolled in the element chemistry course for the 2023-2024 and 2024-2025 academic year in the cities of Bandung and Bandar Lampung.

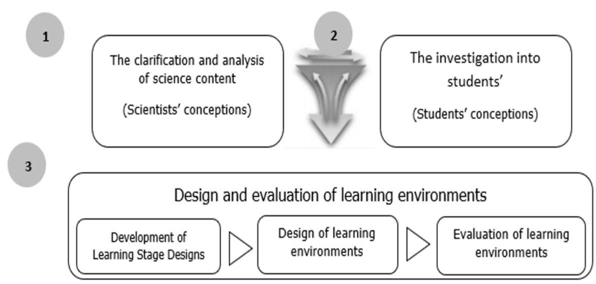

Fig.1. Research design derived from the Model of Educational Reconstruction [6]

3 Result and Discussion

3.1. The Clarification and Analysis of Scientists' Content

This research begins with the clarification and analysis of scientists' conceptions. Literature (books and journal articles) related to nickel, nickel processing technology, and ionic liquids are used for content analysis to gain an understanding of scientists' conceptions regarding the sustainable metallurgy of laterite nickel. The six study materials that are the focus of this stage are [9 ; 10 ;11 ;12 ; 13 and 14]. From the content analysis of various literature, concepts related to laterite nickel, nickel production processes, and nickel extraction using ionic liquids were identified. The context of laterite nickel, as useful elements, can be presented from concrete to abstract materials, and learning can begin by introducing social, economic, political, and environmental issues. The content analysis revealed that ionic liquids are an alternative solvent for nickel extraction. The results of the System Oriented Concept Map Extension (SOCME) show that nickel, as a complex system, can be integrated into the categories of science, technology, and engineering, and each can be grouped into interconnected systems. The consequence map can be used to develop the design of TLS [15].

3.2. The Investigation into Students'

The second stage carried out according to the MER framework is research on the learning process regarding the topic of sustainable laterite nickel metallurgy among prospective chemistry teachers. This step aims to obtain the prior knowledge of prospective chemistry teachers on the topic. To gain an understanding of students' initial knowledge about sustainable laterite nickel metallurgy, interviews were conducted covering: (1) prior knowledge of chemistry content, the context related to laterite nickel elements, and the relationship between the two; (2) the importance of content and the benefits of studying sustainable laterite nickel metallurgy in chemistry education; and (3) the urgency of having a learning design related to sustainable laterite nickel metallurgy. The material constructs formed from the students' perceptions serve as the foundation for developing the TLS design. The results of the preconception study show that only a portion of students were able to explain their knowledge of nickel in relation to processing technologies and the environmental impacts of such processing. Most students were not able to explain their knowledge of nickel in the context of EILs from a scientific perspective. Moreover, most students were unfamiliar with EILs and their applications for sustainably extracting nickel and other valuable metals. To address this gap, a learning design is needed that applies EILs as environmentally friendly solvents in the teaching process, as this can enhance students' systems thinking skills. By integrating EILs in the context of nickel metallurgy, students can better understand the connections between social, economic, and environmental aspects of nickel and other valuable metal processing in a sustainable manner.

3.3. Design and Evaluation of Learning Environments

The results of the analysis of scientists' conceptions and students' preconceptions form the basis for developing the design of TLS. This section explains the design process of the TLS. Within the MER framework, effective design must take into account the learning needs of students, so the scientific content to be taught needs to be reconstructed and adapted to those needs [16]. As explained in the study by [17], the sources of students' experiences and prior knowledge are proven to be very useful in designing instruction. The design of the TLS for sustainable laterite nickel metallurgy that has been developed is the result of reconstructing the students' learning needs, obtained from the analysis of scientists' conceptions as well as interviews on the preconceptions of prospective chemistry teachers.

3.3.1. Development of Learning Stage Designs

This stage begins with an analysis of the learning outcomes for graduates of the undergraduate chemistry education program, which leads to the identification of the learning outcomes for the topic. These topic-specific learning outcomes are then used as a basis to create sub-learning outcomes that align with systems thinking. In this research, the indicators of systems thinking are based on the Systems Thinking Hierarchy model [18], which include: (1) the ability to identify system components and processes within the system, (2) the ability to identify relationships between system components, (3) the ability to identify dynamic relationships within the system, (4) the ability to organize system components and processes within a framework of relationships, (5) the ability to understand the cyclical nature of the system, (6) understanding hidden dimensions of the system, (7) the ability to make generalizations, and (8) temporal thinking: retrospection and prediction. The research-based approach used [19] aims to encourage students to actively engage in the discovery process. Through this approach, students do not merely receive information but are also encouraged to analyze and conduct their own experiments to find answers to scientific issues regarding laterite nickel.

Figure 2 illustrates the overall structure of the learning stage design for the topic of sustainable laterite nickel metallurgy. This design is primarily aimed at enhancing students' systems thinking skills by encouraging active engagement in addressing the environmental challenges posed by laterite nickel, offering solutions through relevant chemical content.

Each component of the design is analyzed, starting from the formulation of learning objectives, assessment, to the expected outcomes. The learning steps outlined in this design follow a research-based approach [19], emphasizing a holistic understanding of the topic from multiple scientific disciplines. This not only includes the physical and chemical properties of nickel, its abundance, and applications, but also covers the future prospects of nickel, recycling efforts, processing technologies, sustainable extraction methods, and the unintended consequences of nickel-related technologies.

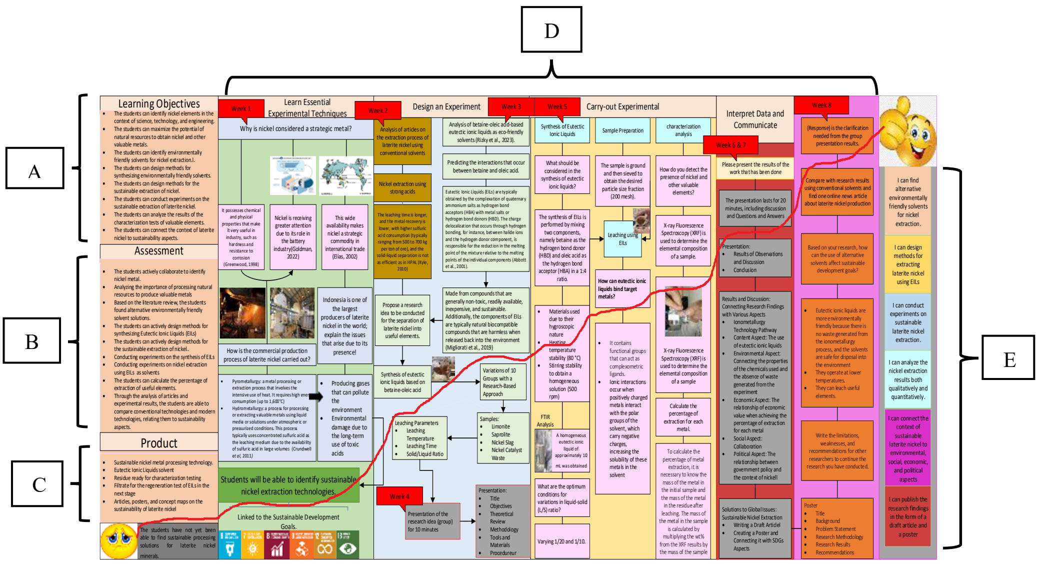

Fig.2. Overview of the TLS design for sustainable laterite nickel metallurgy.

Figure 2 outlines the learning stage design for the topic of sustainable laterite nickel metallurgy. This design includes interconnected components. (A) The targeted learning objectives to be developed. (B) Assessment refers to the evaluation process based on systems thinking skills that are integrated into each step or stage of the learning process. This assessment aims to measure students' system thinking skills. (C) The outcomes produced from the learning process, designed based on a research-based approach. These outcomes may take various forms such as sustainable laterite nickel processing technology projects, creative products like practical experiment videos, research reports such as lab reports, draft articles, and posters. (D) The steps of learning over 8 sessions (Based on the Research-Based Approach). Each box represents one step in the module and corresponds to research-based steps. The steps move from one to the next, as indicated by the arrows and (E) The expected learning outcomes to be mastered by the students.

3.3.2. Design of Learning Environments

The developed teaching learning sequence design is also tailored to the pedagogical framework of research-based lecture steps [19], which includes four stages: Stage 1 (Learning Experimental Techniques): This stage takes place over two weeks and serves as the initial phase in the developed design. It begins with an introduction to issues related to the topic of nickel. Learning should progress from concrete to abstract, and from simple materials to more complex ones. Based on this, the developed teaching stages should start by introducing issues related to nickel processing before moving on to the learning material. Issues that can be found in the topic of laterite nickel include social, economic, environmental, and political aspects. Social issues are presented by discussing the usefulness of laterite nickel in the industrial field. The properties of nickel, which is hard yet elastic, corrosion-resistant, and has high melting and boiling points, make this metal widely used in industry. This connection can be illustrated in content about the physical and chemical properties of nickel. Economic issues can be introduced through the increasing demand for electric vehicle batteries, which are considered a solution to reduce carbon emissions, thereby directly increasing battery demand. The content can include information on the uses of nickel. Political issues can address government regulations regarding nickel downstream processing, as Indonesia is the largest producer of laterite nickel. Thus, the content about nickel abundance can be introduced to students, alongside important information about the formation process of laterite nickel. Environmental issues can be presented through online news discussing the technology pathways for nickel processing and their impacts on the environment. Content that can be presented includes the technology pathways for nickel processing, namely pyrometallurgy and hydrometallurgy, and the unintended consequences of these industrial processes. After introducing these issues, the images in the Power Point slides can be used to illustrate the connection between social, economic, environmental, and political factors related to laterite nickel processing. These visuals will help students understand the complex relationships between various factors influencing the sustainable management of laterite nickel. Moreover, the visualization will clarify how each issue plays a role in determining the most suitable processing methods, both from a technological and environmental sustainability perspective.

Fig.3. Presentation of social, economic, political, and environmental issues.

Stage 2 (Designing an Experiment): This stage is conducted over a period of 3 weeks. The initial step involves presenting content on EILs, followed by students being asked to analyze articles related to this solvent. Additionally, students are tasked with analyzing articles on nickel extraction using conventional solvents. From these two articles, students are expected to generate research ideas, particularly focusing on sustainable nickel extraction using environmentally friendly solvents. Students are then required to present their experimental design in a 10-minute presentation. A confirmation stage can be carried out by watching a video demonstration of nickel extraction using EILs as a solvent.

Stage 3 (Conducting the Experiment): Collaboratively, students will carry out their research plans over the course of one week. The experiments will involve sample preparation, synthesis of EILs solvent, extraction of samples using EILs, and separation of residue and filtrate after extraction.

Stage 4 (Interpreting Data and Communicating Results): For two weeks, students will present their research results by analyzing the characterization test data conducted and relating the research findings to social, economic, environmental, and political aspects. In the final meeting, necessary clarifications regarding their research results will be made.

3.3.3. Evaluation of Learning Environments

Before implementation, an evaluation of the product was conducted using a triangulation technique among assessors both quantitatively and qualitatively, involving three individuals: one chemistry expert and two pedagogical experts. The evaluation results provided feedback for improvement, which became a consideration for product enhancement. The results of triangulation between assessors are shown in Table 1

Table 1. Results of Triangulation Among Assessors Regarding the TLS Design

Assessment Aspects	Week								Average
	1	2	3	4	5	6	7	8	
Alignment of Learning Design Components with Learning Outcome Indicators	4	4	4	4	4	4	4	3	**3.86**
Alignment of Learning Outcome Indicators with Instructions in the Learning Design	3.33	3.67	4	4	4	4	3	3.75	**3.75**
Alignment of Instructions in the Learning Design with SDGs Aspects	4	4	4	4	4	4	4	4	**4**
Alignment of Instructions in the Learning Design with System Thinking Indicators	4	4	4	4	4	4	3.67	3.96	**3.96**

From the evaluation results conducted by the experts, it can be concluded that the developed learning design demonstrates very good alignment with the learning outcome indicators. This alignment is evident in several aspects: (1) Integrated Learning Design Components: The components of the learning design are well integrated to achieve the learning objectives, ensuring that each element supports an effective learning process. (2) Alignment of Learning Outcome Indicators: The learning outcome indicators are aligned with the instructions in the design, creating clarity and focus in evaluating student achievement. (3) Integration of SDGs Aspects: The integration of SDGs aspects into the learning design makes the learning process not only academically relevant but also contributes to sustainable development, enhancing social and environmental awareness among students. (4) System Thinking Approach: The application of a system thinking approach in the instructions enables students to understand the interconnections among components in a broader context, equipping them with system thinking skills.

Thus, this learning design is not only effective in achieving educational goals but also relevant to current global challenges. Recommendations for further research include testing the implementation of this design in different contexts and evaluating its impact on student learning outcomes.

The next step involves applying the learning using research-based TLS to enhance system thinking skills. Data will be collected by administering a final response questionnaire to prospective chemistry teachers regarding sustainable laterite nickel metallurgy, involving 60 students at state universities in Bandung and Bandar Lampung. The results of the questionnaire that capture the researchers' attention will lead to interview stages. The percentage of students' perceptions of the course can be seen in Figure 4.

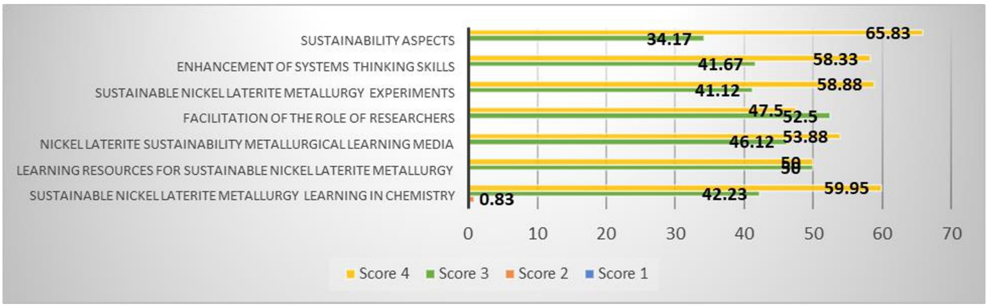

Fig.4. Graph of Final Student Responses to Learning.

The final responses from prospective chemistry teachers regarding the learning of sustainable laterite nickel metallurgy show that almost all aspects fall into the very good category, with more than 50% approval. However, the aspect of facilitation of the role of researchers received a good rating. From the interview results, it was found that in the aspect of students as researchers, they still need more time to explore their research activities further, considering the many limitations in the research they conducted and the need for comparisons or variations in the practical parameters they used. This is important to assess the effectiveness of EILs solvents in extracting metals. Moreover, in the aspect of sustainable nickel laterite metallurgy learning in chemistry, the percentage has shown a very good category, but there are still some students who rated it as less satisfactory. This difficulty stems from the students' challenges in understanding the reaction mechanisms when forming EILs, particularly in grasping the concepts of intramolecular and intermolecular forces during the formation of EILs, which necessitates additional time for learning this content.

4 Conclusions

The scientific concepts regarding the context of sustainable laterite nickel metallurgy were derived from the isolated content presented on nickel, metallurgy chemistry, and ionic liquids, serving as a foundation for developing the learning sequence design. The results indicated that students' preconception skills in systems thinking were still low, necessitating a learning design that incorporates EILs as environmentally friendly solvents. This context can be presented from concrete materials to abstract materials, beginning the learning process by introducing social, economic, political, and environmental issues. The evaluation results from experts on the learning sequence design indicate a very good category. Students' perceptions also show very good and good ratings in each aspect of learning. The chemistry education curriculum can consider using a research-based approach in the learning sequence design within the context of sustainable laterite nickel metallurgy in practice to enhance students' systems thinking skills.

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