Recycling of Rare Earth Elements from Cathode Ray Tube Waste Using Eutectic Ionic Liquids: Laboratory Activity for the Vocational Students to Support Sustainable Development Goals (SDGs)

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Abstract- **This study investigates the effectiveness of a laboratory activity designed to enhance vocational students' understanding of rare earth metal extraction from electronic waste, specifically Cathode Ray Tube (CRT) waste using Eutectic Ionic Liquids (EILs). The method is pre-experiment with one group pretest-posttest design. The research involved 15 chemical engineering students from the Polytechnic in Bandung. The laboratory activity involved collecting CRT waste, separating phosphorus material, synthesizing EILs, extracting rare earth metals from phosphorus material, and observing and analyzing the results. The data analysis technique used was descriptive analysis of N-Gain and statistical tests like the normality test and non-parametric Wilcoxon test. The results showed a medium increase in learning outcomes with a 28% and the N-Gain value for learning outcomes is 0.59. The Wilcoxon statistical test confirmed the significant difference between learning outcomes before and after the laboratory activity. The study concludes that this novel laboratory activity is effective in increasing students' understanding of sustainable rare earth metal extraction, It aligns with Sustainable Development Goals No. 12: Responsible Consumption and Production, providing a solution to the e-waste problem and serving as an educational tool for sustainable practices.**

Keywords- **Cathode Ray Tube Waste; Eutectic Ionic Liquid; Laboratory Activity; Rare Earth Metals Extraction; Recycling; Supporting SDGs; Vocational Students**

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I. INTRODUCTION

Laboratory activities are important in education, particularly in science and engineering, because they provide students with hands-on experience and practical skills relevant to their chosen field (Al Husaeni et al., 2024; Ana, 2020; Patil and Chavan, 2020; Rosina et al., 2021). Students can observe, question, formulate hypotheses, conduct experiments, analyze data, and draw conclusions in laboratory activities (Kapici et al., 2020; Ramesh and Fusic, 2024). This hands-on experience not only improves their understanding of complex scientific concepts but also promotes critical thinking, problem-solving abilities, and the ability to collaborate (Agustian et al., 2022; Demirhan and Şahin, 2021). Furthermore, laboratory activities are designed to reinforce theoretical learning, bridging the gap between classroom teaching and real-world application by allowing students to apply classroom knowledge to real-world situations, making the learning process more relevant and engaging (Kapici et al., 2020; Kong et al., 2022).

The laboratory activity is very useful in vocational education which prioritizes practice (Fajra and Novalinda, 2020; Patil et al, 2022; Sukandar et al., 2020). One practice that often goes unnoticed and is not yet efficient is recycling, especially recycling electronic waste. In this case, the 4R concept (Reduce, Reuse, Recycle, and Replace) needs to be taught more deeply and innovatively to vocational students (Pérez, 2023; Theis, 2021). Cathode ray tube (CRT) waste is one type of electronic waste that is usually ignored because it has been surpassed in the market by flat screen technology. As a result, many CRTs are discarded, becoming electronic waste that continues to accumulate (Singh et al., 2016).

CRT waste recycling is an intriguing topic because CRTs contain phosphorous materials containing rare earth metals, as well as metals that can be harmful to the environment if not properly managed. This phosphorus material can be recycled and repurposed by extracting rare earth metals (Alvarado-Hernández et al., 2019; Yin et al., 2018). Recent research also shows that rare earth metals can be extracted in a simple and efficient treatment using more environmentally friendly ionic liquids (Kaim et al., 2023; Pereira Neves et al., 2022; Prusty et al., 2021; Rizky et al., 2024; Widyaningsih et al., 2024). This contributes to a more sustainable and environmentally friendly waste management approach. Those methods can be included in laboratory activities for vocational students for electronic waste recycling. In this study, the laboratory activity includes students collecting CRT waste and separating the phosphorus material, then using ionic liquids to extract rare earth metals from this phosphorus material. Throughout the activity, students are guided to observe and understand the extraction process thereby increasing their understanding of rare earth metal extraction and discussing the implications for environmental sustainability and the rare earth metal supply chain.

This laboratory activity is also in line with the Sustainable Development Goals (SDGs), especially Goal No. 12: Responsible Consumption and Production (Maulana et al., 2023). By studying and participating in laboratory activities on CRT waste recycling, students gain a deeper understanding of the importance of responsible consumption and production. Research on SDGs is one of the attractive subjects (Kirupa et al., 2024; Nurramadhani et al., 2024; Makinde et al., 2024; Gemil et al., 2024; Haq et al., 2024; Basnur et al., 2024). Students also learn about the value of rare earth metals and the importance of electronic waste recycling. Several studies have also carried out laboratory activities to increase students' understanding of vocational education, such as battery basics hands-on experiments (Steger et al., 2020), laboratory kit of air conditioning process (Berman et al., 2021), at-home laboratory experiments of biomaterials (Panebianco, 2021); hands-on laboratory on voltage and current measurements (Rahman and Johari, 2022), and hands-on science laboratory (Kapici et al., 2022). The purpose of this study is to design a novel laboratory activity to increase vocational students' understanding of rare earth metal extraction for CRT waste recycling to support SDGs. Through hands-on experience from this laboratory activity, students will gain a deeper understanding of the importance of recycling and sustainable practices that are in line with the SDGs in the context of electronic waste management. Furthermore, this activity aims to inspire students in future innovations in the field of waste management and rare earth metal extraction to contribute to a more sustainable future.

II. Theoretical Framework

2.1. Issues of Waste Recycling Using Sustainable Material in Vocational Education

In an era of rapid technological progress, electronic waste has become a significant concern because the amount is increasing from year to year. Among them, cathode ray tube waste (Cathode Ray Tube, CRT) was the main technology used in televisions and computer monitors before the advent of flat screen displays. Although most of the CRTs have been replaced in the market, a large amount of waste CRTs still exist. As a result, CRT devices accumulate as electronic waste in large quantities, giving rise to new problems. Recycling of CRT waste is a topic that attracts attention because it contains phosphorus. This phosphorus material contains rare earth metals such as Yttrium and Europium which are valuable resources. Rare earth elements (REEs) are a group of 17 elements consisting of lanthanides, yttrium, and scandium (Peiravi et al., 2021; Rizky et al., 2024). Apart from that, there are also dangerous metals in it, such as lead, barium, and strontium (Ciftci and Cicek, 2017). These metals, although valuable, are often wasted due to a lack of efficient and environmentally friendly extraction methods.

Issues related to waste recycling must be conveyed and addressed appropriately. In this case, vocational education such as chemical engineering, materials engineering, metallurgical engineering, waste management, and other similar fields are certainly very concerned about those issues. They have a responsibility to promote green industry practices and techniques, as well as sustainable development in society. However, given the significant environmental impact of negative industrial practices, learning in vocational education still has many shortcomings that must be addressed. The incorporation of green skills into learning is important to address these issues. Based on the learning outcomes of vocational student graduates in general, vocational students are expected to have capable in facing industry (Maryanti and Nandiyanto, 2021; Minghat et al., 2023; Shahroni et al., 2022; Anwar and Minghat, 2024; Hashim et al., 2024). There are several criteria:

(i) Capable of identifying, formulating, analyzing, and solving complex engineering problems.
(ii) Capable of finding the root cause of engineering problems in processes, processing systems, and equipment required to convert raw materials into products with added value via an investigation, analysis, and interpretation of data and information based on engineering principles.
(iii) Capable of selecting and utilizing appropriate information and computing technology-based engineering design and analysis tools to carry out engineering activities in the field of processes, processing systems, and equipment required to convert raw materials into products with added value.
(iv) Capable of designing and carrying out laboratory and/or field experiments, as well as analyzing and interpreting data to strengthen engineering assessments.
(v) Capable of conducting research that includes identifying, formulating, and analyzing engineering problems in processes, processing systems, and equipment required to convert raw materials into products with added value.

(vi) Capable of developing alternative solutions to complex engineering problems in processes, processing systems, and equipment required to meet expected needs within realistic constraints, such as legal, economic, environmental, social, political, health and safety, and sustainability, as well as recognizing and/or utilizing the potential of local and national resources with a global perspective.

In the context of metal extraction, vocational students are expected to have the following criteria.

(i) Students must understand the fundamental concepts and principles underlying the metal extraction process.
(ii) Students are expected to learn various metal extraction techniques and methods.
(iii) Students must be able to design and optimize metal extraction processes while considering factors such as efficiency, cost, and environmental impact.
(iv) Students are expected to understand and apply good safety practices in the metal extraction process, as well as to comprehend the process's environmental impacts.
(v) Students are expected to stay up to date on the latest developments in metal extraction, such as new technologies and current issues.

Students will gain practical skills in handling and recycling electronic waste by participating in this laboratory activity, which will help them achieve the learning outcomes of vocational student graduates. Students can also learn about the use of eutectic ionic liquids and the significance of sustainable waste management practices. This activity is an important step toward empowering students to be responsible and innovative contributors to society's sustainability efforts.

2.2. Rare Earth Metals Extraction Using Eutectic Ionic Liquids

Rare earth metals are valuable and strategic metals that have been widely used along with the development of smart technology. Because this metal is difficult to mine, the recovery of this metal from secondary resources has undergone further development (Filho et al., 2023). There are various recycling methods available to extract these rare earth metals. Traditional methods for the extraction of REEs typically include hydrometallurgy, electrometallurgy, and pyrometallurgy, which are used to separate rare earth element oxides (REO) from mineral concentrates (Jha et al., 2016; Stopic and Friedrich, 2021). Physical separation methods such as gravity separation, magnetic separation, and electrostatic separation are also commonly used (Moghiseh et al., 2016; Suli et al., 2017). Some elements can be extracted by the reduction distillation method, while other elements can be extracted by the electrolysis method or reduction method (Lai et al., 2023; Venkatesan et al., 2018). The extraction of rare earth metals is a complex process due to the similarity of the elements. Traditional pyrometallurgical and hydrometallurgical processing techniques, although widely used in the recovery of REEs, have several environmental drawbacks. Traditional methods are time-consuming, expensive, and produce large amounts of toxic waste. Therefore, new recovery approaches are being intensively developed. Solvometallurgy has emerged as an environmentally friendly technology, and ionic liquids and deep eutectic solvents have become first-line chemicals used in various unit operations used in solvometallurgical processing (Arrachart et al., 2021; Binnemans and Jones, 2017).

There are recent studies proposing a more environmentally friendly method for extracting and separating rare earth metals using eutectic ionic liquids (EILs) which presents a potential solution to this problem. EILs, the next generation of ionic liquids, have a unique structure with both ionic and non-ionic species and a hydrogen bond network. EILs offer simple, environmentally friendly, low-cost, and higher efficiency production, suitable for large-scale production (Rizky et al., 2024; Widyaningsih et al., 2024). EILs have proven effective in extracting rare earth metals from a variety of sources, including phosphorus material in CRT waste. In comparison to conventional organic solvent extraction systems, ionic liquid extraction systems benefit from ionic liquids' affinity for charged and neutral hydrophobic species. Complexes extracted in IEL extraction systems are frequently different from complexes extracted in organic solvent systems, and the extraction and separation efficiency of REEs is frequently significantly improved. To address REE supply challenges, researchers are looking into recovering REEs from waste using ionic liquids as environmentally friendly diluents and extractants (Alguacil and Robla, 2023; Arrachart et al., 2021).

III. Method

3.1 Research Design

This study is pre-experiment research. The design of this study is one-group pretest-posttest design. In this study, student learning outcomes were measured twice, namely, before and after giving treatment in the form of laboratory activities regarding the extraction of rare earth metals using eutectic ionic liquids. Assessment of learning outcomes is based on an assessment rubric for the pretest-posttest test which consists of 5 identical essay questions. Each question has keywords and answer criteria that suit the context of each question. Table 1 presents each question item from the pretest-posttest and the assessment guidelines for this test are presented in Table 2.

TABLE I
PRETEST-POSTTEST QUESTION ITEMS

No.	Questions
1	Explain why rare earth metals are critical metals.
2	What are the secondary sources of rare earth metals? In your opinion, what is the most suitable secondary source to address the rare earth metal supply problem? Why?
3	What is the most appropriate method for extracting rare earth metals and what is the process for extracting rare earth metals using ionic liquids?
4	What are the characteristics of a good solvent for extracting rare earth metals from cathode ray tube waste? Compare conventional ionic liquids with eutectic ionic liquids!
5	How do you detect and analyze the presence of rare earth metals in television cathode ray tube waste?

TABLE II
PRETEST-POSTTEST ASSESSMENT GUIDELINES

Score	Assessment criteria
0	No answer or wrong answer
5	Answers without answer keywords or criteria
10	Answers that only contain one keyword or criteria
15	Answers with answer keywords and criteria, but incomplete
20	Answers with complete answer keywords and criteria

3.2 Research Subjects

The subjects of this research were students majoring in chemical engineering at the Polytechnic in Bandung. The samples in this study were 15 students. The research subjects were chosen from students majoring in chemical engineering because the curriculum of this department generally includes learning outcomes related to metallurgical processes that must be mastered by students. In this case, the topic of metal extraction is indeed very important. Besides that, with the SDGs, of course, these learning achievements must be supported by sustainable practices, especially for students majoring in chemical engineering who are destined to enter the industry for their future career path.

3.3 Experimental Teaching and Learning Method

Students are given treatment stages according to Table 3. Students start by completing a pretest first to identify their previous knowledge regarding rare earth metal extraction. Next, entering the laboratory activity stage, students are given directions to be able to carry out experiments based on student worksheets. During this stage, the instructor also guides students to carry out their experiments. After laboratory activities are completed, students are asked to complete a post-test to identify the success of implementing laboratory activities on their knowledge.

TABLE III
THE SUMMARY OF THE EXPERIMENTAL METHOD OF TEACHING DELIVERY

Delivery Method	Description	Role Action
Pre-teaching	Pre-test	Students
Content Delivery	Laboratory Activity	Students
Post-teaching	Post-test	Students
Conclusion	Question and Answer	Lecturer-Students

3.4 Laboratory Activity Design

The main objective of laboratory activities is to provide students with direct experience regarding the extraction of rare earth metals from electronic waste in the form of phosphorus materials in CRT waste using EILs based on sustainable practices following SDGs in Goal 12: Responsible Consumption and Production. The set of experimental equipment assembled and used in this laboratory activity is shown in Figure 1. This experiment uses a sand bath placed on a hot plate for heating and is equipped with a magnetic stirrer for stirring. In the sand bath, there is a Schlenk tube as a reaction container, and is also equipped with a thermometer. Figure 2 shows a scheme of the main stages in this laboratory activity. This laboratory activity consists of the following main stages.

(i) CRT Waste Collection: Students can start by collecting CRT waste which can come from discarded televisions or computer monitors. In this study, CRT waste was provided by the instructor.
(ii) Separation of Phosphorus Material from CRT Waste: Phosphorus material behind the CRT glass panel is separated from CRT waste. Students are given guidance on how to separate and pretreat phosphorus materials by the instructor.
(iii) Eutectic Ionic Liquid Synthesis: Students carry out experiments based on student worksheets to synthesize eutectic ionic liquids which will be used as solvents in the extraction of rare earth metals from phosphorus material samples.
(iv) Rare Earth Metal Extraction: Students carry out experiments based on student worksheets to extract rare earth metals in samples of phosphorus materials using synthesized ionic liquids.
(v) Observation and Analysis: Throughout the experimental process, students are guided by the instructor to observe and understand each synthesis and extraction process.

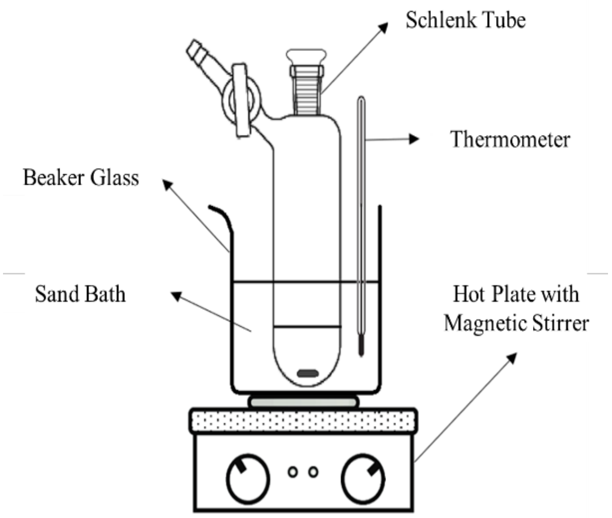

Fig. 1. Experimental Apparatus Set

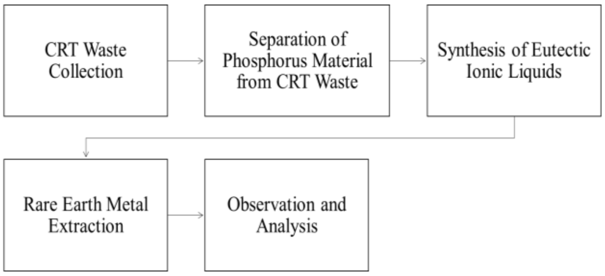

Fig. 2. Scheme of The Main Stages of Laboratory Activity

3.5 Data Analysis

The data obtained from this research was then processed and analyzed with the help of Microsoft Excel and IBM SPSS Statistics Version 26 software. Detailed information regarding the use of SPSS is explained elsewhere (Fiandini et al., 2024)). The following are several statistical tests carried out in this research.

3.5.1 N-Gain Test

The purpose of the N-Gain test is to determine the increase in student learning outcomes before and after laboratory activities. The formula for calculating N-Gain (g) is shown in (1) and the N-Gain index categories are presented in Table 4 where if g > 0.70, student learning outcomes increase greatly; if 0.30 ≤ g ≤ 0.70, the increase in student learning outcomes is in the medium category; and if g < 0.30, the increase in student learning outcomes is in the low category.

$$N-Gain = \frac{((post-test\ score)-(pre-test\ score))}{((score\ ideal)-(pre-test\ score))} \times 100 \quad (1)$$

TABLE IV
N-GAIN INDEX CATEGORY

Limitation	Category
g > 0.70	High
0.30 ≤ g ≤ 0.70	Moderate
g < 0.30	Low

3.5.2 Validity Test

Validity tests are carried out to ensure the extent to which the research instruments used, namely the pretest and posttest, can measure student learning outcomes. The validity of each test question is measured using Pearson product-moment correlation. Table 5 presents the results of the validity test. The conclusion is that if rcount > rtable, the question is declared valid. The degree of freedom in this study is 13. Thus, the rtable value is 0.514. A summary of the validity test results is presented in Table 6.

TABLE V
VALIDITY TEST ON THE ITEM QUESTIONS

No. Question	r_{count}	r_{table}	Description
1	0.744	0.514	Valid
2	0.769	0.514	Valid
3	0.234	0.514	Unvalid
4	0.901	0.514	Valid
5	0.888	0.514	Valid

TABLE VI
SUMMARY OF VALIDITY TEST

Type	Note
Number of questions	5
Number of students	15
Number of valid questions	4 (Question No. 1, 2, 4, and 5)
Number of invalid questions	1 (Question No. 3)

3.5.3 Reliability Test

Reliability testing is carried out to determine the consistency of repeated measurement results. Thus, the results of the research instruments used can be relied upon. The reliability of the pretest-posttest test was measured using Cronbach's Alpha. Table 7 presents the categorization of reliability values and Table 8 presents the results of the reliability test in this study. Based on this, the reliability of the pretest-posttest is high.

TABLE VII
RELIABILITY CATEGORIZATION

No.	Reliability Value	Category
1	0.8-1.0	Very High
2	0.60-0.79	High
3	0.40-0.59	Moderate
4	0.20-0.39	Low
5	< 0.19	Very Low

TABLE VIII
RELIABILITY TEST ON THE ITEM QUESTION

Type	Note
r_{count}	0.778
Category	Reliable (High)

3.5.4 The Questions Difficulty Level Test

The question difficulty level test is carried out to find out the proportion of students who can answer the question correctly. Thus, they can determine whether the question is easy or difficult. The level of difficulty (P) of the essay questions in this pretest-posttest is determined based on the formula in equation (2).

$$P = \frac{Mean\ Score}{Maximum\ Score} \quad (2)$$

The difficulty level index for the questions in this study was determined based on the criteria of Robert L. Thorndike and Elizabeth Hagen in Table 9. The results of the test for the difficulty level of these questions are shown in Table 10. Based on this, the difficulty level of all the questions is in the medium category.

TABLE IX
DIFFICULTY INDEX CATEGORY

Limitation	Category
> 0.70	Easy
0.30-0.70	Medium
< 0.30	Difficult

TABLE X
DIFFICULTY LEVEL OF PRETEST QUESTIONS

No. Question	Mean Score	Maximum Score	Difficulty index value	Question category
1	10	20	0.50	Medium
2	11,33	20	0.56	Medium
3	10,33	20	0.51	Medium
4	11,67	20	0.58	Medium
5	8	20	0.40	Medium

3.5.5 Normality Test

The normality test must be carried out first to be able to determine the choice of statistical test to be carried out next, whether a parametric or nonparametric test. In parametric tests, the data used must be normally distributed, while nonparametric tests do not specifically require normally distributed data.

3.5.6 Significance Test

In this study, data analysis was carried out to compare the mean pretest and post-test scores, and the data in the one group pretest-posttest design is paired. Thus, the choice of significance tests that can be carried out is the paired t-test if the data is normally distributed and the Wilcoxon test if the data is not normally distributed.

IV. RESULTS AND DISCUSSION

4.1. Descriptive Analysis of Learning Outcomes

In this section, descriptive analysis will provide a detailed explanation regarding the learning outcomes that have been achieved by students through the laboratory activities that have been carried out. These learning outcomes are measured from pretest and posttest scores. Table 11 shows the percentage of post-test scores and classification of questions based on Bloom's Taxonomy. In addition, students' pretest and posttest scores were also compared and analyzed to determine improvements in student learning outcomes using the N-Gain formula. Table 12 presents the N-Gain value data from the student's learning outcomes, while a detailed description of the pretest and post-test scores is presented in Table 13.

TABLE XI
POST-TEST SCORE OF EACH ITEM QUESTION

No.	Question Problems	Bloom Taxonomy	Score (%)
1	Rare earth metals are critical metals.	C2	86.67
2	The most suitable secondary source to address rare earth metal supply issues.	C3	83.33
3	The most appropriate method for rare earth metal extraction and the rare earth metal extraction process uses ionic liquids.	C4	80
4	Characteristics of good solvents for extracting rare earth metals from cathode ray tube waste and comparison between conventional ionic liquids and eutectic ionic liquids.	C5	80
5	How to detect and analyze the presence of rare earth metals in television cathode ray tube waste.	C6	66.67

Based on Table 11, the percentage of posttest scores tends to decrease as the bloom taxonomy category in the questions increases. Question 1 only contains C2 which is limited to understanding. Thus, the percentage of posttest scores is the largest, namely 86.67% because it was the easiest. Next, the level of Bloom's taxonomy in questions increases, namely C3 (Applying), C4 (Analyzing), C5 (Evaluating), and finally question 5 contains C6 which emphasizes creating or creation. Question 5 is of course the most difficult question when referring to Bloom's taxonomy and this is also proven by the lowest percentage of posttest scores, namely 66.67%.

Based on Table 12, the difference between the average score of the post-test and the pretest is 28. This shows that there is a percentage increase in learning outcomes through laboratory activities, namely 28% of the ideal score of 100. Furthermore, the average N-Gain value of the learning outcomes is overall 0.59 and is included in the medium category. This means that the laboratory activities that have been carried out also improve student learning quite effectively. 3 students got high N-Gain scores (20%) and the remaining 12 students got medium N-Gain scores (80%). Based on this data, all students' understanding regarding the extraction of rare earth metals increased well and there were no students who had a low increase in understanding. Besides that, based on Table 13, the lowest score obtained also increased from 30 on the pretest to 70 on the posttest, and the highest score obtained also increased from 70 on the pretest to 95 on the posttest.

TABLE XII
N-GAIN VALUE OF STUDENT LEARNING OUTCOMES

No.	Student Code	Pre-test	Post-test	N-Gain	Category
1	A1	45	75	0.55	Moderate
2	A2	65	90	0.71	High
3	A3	65	85	0.57	Moderate
4	A4	70	95	0.83	High
5	A5	45	75	0.55	Moderate
6	A6	60	85	0.63	Moderate
7	A7	30	70	0.57	Moderate
8	A8	35	70	0.54	Moderate
9	A9	45	75	0.55	Moderate
10	A10	50	70	0.40	Moderate
11	A11	55	75	0.44	Moderate
12	A12	40	75	0.58	Moderate
13	A13	40	75	0.58	Moderate
14	A14	65	90	0.71	High
15	A15	60	85	0.63	Moderate
Mean Score		**51.33**	**79.33**	**0.59**	**Moderate**
Standard Deviation		**12.459**	**8.209**	**0.1057**	

TABLE XIII
THE DETAIL DESCRIPTION OF PRETEST AND POSTTEST SCORES

Data Type	Pre-test	Post-test
Respondent	15	15
Highest score	70	95
Lowest score	30	70
Ideal score	100	100
Average score	51.33	79.33
Standard deviation	12.459	8.209

4.2. Statistical Analysis of Learning Outcomes

Statistical test analysis was carried out to further confirm and confirm the results of descriptive analysis of previous learning outcomes. The normality test is carried out first to determine the choice for the significance test.

4.2.1 Normality Test

The normality test is intended to see the distribution of pretest and posttest scores data. This data was tested using the Shapiro-Wilk normality test because the amount of data was less than 50, that is, there were only 15 student pretest-posttest scores. The normality test results are presented in Table 14. Conclusions are based on the Shapiro-Wilk significance value, if the Sig. is greater than 0.05, the data is normally distributed, whereas if the Sig. less than 0.05, the data is not normally distributed.

TABLE XIII
NORMALITY TEST RESULTS

Tests of Normality			
	Shapiro-Wilk		
	Statistic	df	Sig.
Pretest	0.942	15	0.403
Posttest	0.866	15	0.030

Based on Table 14, the Sig. in the pretest is 0.403 > 0.05. Thus, the pretest value data is normally distributed, while the Sig. on the posttest is 0.030 < 0.05, Thus the posttest value data is not normally distributed. Thus, because one of the data is not normally distributed, the significance test chosen is a non-parametric test in the form of the Wilcoxon test.

4.2.2 Significance Test

The purpose of a significance test is to test a hypothesis of a relationship or comparison between two or more variables. In this study, a significance test was carried out to determine whether or not there was a difference between learning outcomes before (pretest scores) and after (posttest scores) laboratory activities given to students. The basis for decision-making is if the Sig. < 0.05, H_0 is rejected and H_1 is accepted, and if the Sig. > 0.05, H_0 is accepted and H_1 is rejected. The hypothesis of this significance test is as follows.

(i) H_0 = there is no difference between learning outcomes before and after laboratory activities
(ii) H_1 = there is a difference between learning outcomes before and after laboratory activities.

Because the data is not completely normally distributed in the normality test, the significance test used is the Wilcoxon test. The results of the Wilcoxon Signed Ranks Test are presented in Table 15 and the results of the Wilcoxon statistical test are presented in Table 16.

TABLE XIV
WILCOXON SIGNED RANKS TEST RESULTS

Ranks				
		N	Mean Rank	Sum of Ranks
Posttest – Pretest	Negative Ranks	0[a]	.00	.00
	Positive Ranks	15[b]	8.00	120.00
	Ties	0[c]		
	Total	15		

a. Posttest < Pretest
b. Posttest > Pretest
c. Posttest = Pretest

Based on Table 15, the negative ranks or negative differences between the pretest and posttest results have a value of 0. Thus, there is no decrease from the pretest to posttest scores. Furthermore, the positive rank value or the positive difference between the pretest and post-test results has an N value of 15, a Mean Rank value of 8, and a sum of ranks value of 120. This means that all 15 students experienced an increase in learning outcomes from pretest to post-test scores and the average improvement is 8. Lastly, ties show the similarity between the pretest and posttest scores. The tie value is 0, meaning there is no equal value between the pretest and posttest.

TABLE XV
WILCOXON STATISTICAL TEST RESULTS

Test Statistics[a]	
	Posttest - Pretest
Z	-3.430[b]
Asymp. Sig. (2-tailed)	0.001

Based on Table 16, if the Sig. is 0.001 < 0.05, H_1 is accepted, meaning that there is a difference between learning outcomes before and after laboratory activities. Thus, the conclusion is that the laboratory activities that have been carried out have indeed succeeded in improving student learning outcomes effectively, namely in understanding rare earth metal extraction.

CONCLUSION

The new laboratory activity that has been designed has succeeded in improving student learning outcomes on the topic of rare earth metal extraction based on the results of descriptive analysis and statistical tests. The average N-Gain value obtained is 0.59. Thus, the increase in student learning outcomes is in the medium category overall. Based on the percentage of pretest and posttest scores, the increase in learning outcomes was 28%. This has also been confirmed in statistical tests which show that there is a significant difference between learning outcomes before and after laboratory activities. This laboratory activity in the form of recycling phosphorus material in CRT waste using EILs not only provides a solution to the electronic waste problem but also functions as an effective educational tool to increase student awareness of sustainable practices that contribute to achieving the SDGs.

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