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# SciEd

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# SciEd

SEAQIS Journal of Science Education

Acting Director's Message

Dear readers,

It is my pleasure to once again greet you, our dearest readers, in SEAQIS Journal of Science Education (SciEd) volume 4, issue 1. Through SciEd, SEAQIS realises that teachers and education personnel need a platform to show their innovations in written works. Therefore, we are committed to be a liaison between writers and science-loving readers.

As SEAQIS' vision aims to be the Centre of excellence in the professional development of teachers and education personnel in science towards sustainable development in Southeast Asia, we collaborate with authors from this region to present high-quality and up-to-date research.

I would like to take this opportunity to express my most profound appreciation to the authors, SEAQIS staff, and other parties for their contribution that made this publication possible. I hope that SciEd can make a real contribution to the development of science education in the near and distant future. I also encourage SciEd writers and readers to rise and realise their love for science, one of which is through research. Dare to innovate!

Sincerely,

Zuhe Safitra, M.Pd.
Acting Director, SEAMEO QITEP in Science

From the Editor-in-Chief

Greetings and welcome to the 4th volume, issue 1 in SEAQIS Journal of Science Education (SciEd). Firstly, I extend my sincere appreciation to all the authors, the Editorial Board, the designer, the Publishing Office Staff, and everyone who has contributed to this publication. Your endeavours have been instrumental in bringing this journal to fruition.

Quoting Stephen Hawking, who said, "Intelligence is the ability to adapt to change," I acknowledge that, despite the hard work, there may be areas where improvements can be made in this issue. Therefore, I encourage readers to provide constructive criticism, comments, and suggestions. Your feedback is essential for enhancing the quality of SciEd.

Furthermore, I kindly invite you to contribute to the enrichment of this journal by submitting your best articles for consideration in upcoming volumes. Your contributions will not only improve this journal but also contribute to the broader landscape of scientific understanding.

Thank you for your support and encouragement. Let us, hand in hand, strive for the advancement and enrichment of science education.

Warm regards,

Dr Elly Herliani
Editor-in-Chief

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## SEAQIS Journal of Science Education (SciEd)

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Research Paper Open Accsess

# Investigating The Impact of Acquired Fundamental Laboratory Skills in Chemistry on The Student's Actual Academic Achievement in Rutsiro District of Rwanda

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## Abstract

*The enhancement of fundamental laboratory abilities in advanced learners has multiple implications for academic performance. Corrective action is necessary for secondary school pupils who are taking chemistry as a core subject because of their poor performance in the subject. The aim of this study was to find out how advanced-level learners learned fundamental laboratory skills in chemistry and how those skills affected their academic performance in two secondary schools. In the investigation, an empirical method was applied. Quantitative data were collected and analysed during the data-gathering processes. From the Rutsiro district of Rwanda, mathematical-chemistry-biology and physics-chemistry-biology combinations in chemistry were studied by a sample of senior five learners in advanced secondary education who were studying chemistry as a core subject. Quantitative data were gathered using a closed questionnaire and a positivist approach that uses deductive research. The theory was the starting point, and it was determined whether or not practical laboratory skills had been established. There were186 respondents in the target group, of which 80 were chosen from several secondary schools, one of which was a boarding school (the School of Excellence) with a fully functional chemical lab and the other a 12-year-old BE (Basic Education) that had chemistry kits but no chemistry lab. The Statistical Package for Social Sciences (SPSS) was used to analyse the data. The results of the paired t-test show that the test mean difference (M = 1.363) is less than the school mean difference (M = 1.463). At the 0.001 level of significance, the results of the analysis suggest that the scores for the two means differed statistically significantly (t (79) = 0.000, n = 80, P < 0.001). The results of the statistical test indicate that students' views towards chemistry were somewhat influenced by the fundamental laboratory chemistry practical skills taught in schools. Students who failed practical tests for basic laboratory skills may not have access to well-equipped labs, but their interest in chemistry can be sustained through practical work.*

**Keywords:** Developed fundamental skills; Practical work; Laboratory; Student's performance

## Introduction

Competence-based curriculum (CBC) can be used in secondary schools to teach chemistry, just like other experimental sciences, both theoretically and practically when experiments are involved. Like experimental science, chemistry requires its students to conduct a great deal of practical work and view demonstrations of the subject, as noted by Alanazi (2022). Additionally, Shana and Abulibdeh (2020) contend that engaging in practical work can stimulate students' curiosity about science and help them see it as an interesting subject. An experiment is a test conducted in carefully monitored settings to verify a hypothesis, prove a known fact, or assess the effectiveness of an innovative idea (Kamonmarttayakul et al., 2021).

Students can gain valuable learning experiences via laboratory activity, which serves as a link between the conceptual and the real world as well as between the molecular and macroscales. In addition to increasing students' scientific skills, lab work is crucial for catching their attention (Anwar et al., 2023). The central topic of this research is defined as the fundamental or basic abilities required of students in order to perform chemistry lab work.

For instance, because chemistry is an experimental science, students in advanced secondary schools at senior five (S5) must be able to use a weighing balance to determine the mass of substances, depending on the topics they have covered in their studies found in the Rwanda national curriculum. They should also be aware of the functions of lab apparatus and know how to use them, even if they can only use one. Research indicates that students' lack of academic preparation for laboratory work and the associated risks are the root of the problem with lab work (Sokol et al., 2022). Students are typically the ones involved in laboratory accidents because they lack awareness of the level of risk involved in not understanding worker safety in the lab. (Yuliani et al., 2020). The majority of students may see this as a positive step in the correct direction, but I also saw the report in this research as a tool for noticing the sufficient fundamental skills for laboratory chemistry obtained by attending laboratory work in secondary school.

Nonetheless, most of them encounter particular difficulties in their search for science education, particularly with regard to chemistry. For example, a Rwandan student who excels in chemistry enrols in laboratory and health-related specialised courses. Fewer students are able to pursue careers in chemistry, specifically as a result of their poor performance (MINEDUC, 2018). Although chemistry is a relatively important subject, it is disheartening to see that students' performance in the subject has not improved significantly during examinations, which leads to a national scarcity of experts and insufficient healthcare facilities (Doreen, et.al., 2023).

Chemistry instruction in secondary schools aims to improve student achievement, but Rwandan students have historically performed poorly on national science exams (MINEDUC 2018) and dropped out of chemistry (MINEDUC 2020). To remain competitive in science-oriented jobs, remedial measures must be implemented, including providing highly qualified workers with science and technology training and a solid understanding of chemistry. Chemistry is one of the science courses that opens doors to many careers for secondary school students who want to work in medicine, health science, agriculture, animal medicine, pharmacy, etc. (Kayitesi et al., 2022).

The term "chemistry laboratory practical skills" usually refers to the aptitude for specific tasks in the laboratory. Here, a range of abilities, including experimentation, lab procedures, appropriate tool usage, analytical methods, and problem-solving strategies, are essential for successful chemistry coursework and help students advance their ability to comprehend and conduct scientific inquiry. As a result, students learn by understanding while simultaneously developing their analytical abilities to solve problems
(Garminovich, 2020). Even though laboratory activities are crucial for understanding chemical concepts, they stand out as learning opportunities where students engage with various tools and materials to investigate occurrences (Shana & Abulibdeh, 2020). In order to understand the material in chemistry, the laboratory offers possibilities to "learn by doing"(Mas'ud et al., 2022)

In Rwanda, students enrol in advanced chemistry combinations after completing basic general education courses; however, in secondary schools, poor performance in chemistry continues to be a problem, either at the district level or at the level of individual schools. Ekici & Atasoy (2023) and Ndihokubwayo et *al.* (2022) noted that chemistry is generally a difficult subject to study; thus, students must regularly get chemistry instruction in practical lessons, instructor demonstrations during practice of the material, and the use of learning resources to promote their acquisition of skills. Thus, it is crucial to conduct research to determine the practical skills acquired in basic chemistry labs and how they affect the academic achievement of higher-level secondary school learners. Therefore, the aim of this study is to record secondary school students' fundamental laboratory skills; to ascertain how advanced students who are majoring in chemistry in schools with well-equipped labs and schools lacking a significant lab developed their fundamental skills; and to look into how these developed skills affected the students' practical academic performance.

The fundamental laboratory skills used in this research was based on Salin (2012), which are using a burette, making a standard solution, weighing with an analytical balance, heating substances using a Bunsen burner, using a dropper to measure and transfer liquid, heating with a hot plate or heating mantle, using beakers for holding liquid or solid samples, measuring volumes, using test tubes to burn tiny amounts of substances, using a test tube holder, using crucible tongs or beaker tongs, peaking powder of solids, and filtering.

The goal of the current study was to find out how advanced-level learners learned fundamental laboratory skills in chemistry and how those skills affected their academic performance in two secondary schools. Three goals guided the study: first, to record secondary school students' fundamental laboratory skills; second, to ascertain how advanced students who are majoring in chemistry in schools with well-equipped labs and schools lacking a significant lab developed their basic skills; and third, to look into how these developed skills affected the students' practical academic performance.

## Methodology

### *Research Design*

This study employed a deductive research design to examine the essential practical abilities developed among students at an advanced level (S5) in the lab and their influence on secondary school academic performance. This design involved gathering and assessing data from an accurate representation of the entire group in order to analyse the overall population of the study. A questionnaire and a practical test were used to gather data for research in 12 YBE without a lab but equipped with chemistry kits, as well as in a boarding school with a lab. It examined the state of chemistry instruction in secondary schools today using both qualitative and quantitative methodologies to achieve goals.

### *Research Paradigm*

The term paradigm, which is frequently used in studies on education, refers to the worldview of the researcher (Miedema, 2023). Positivism was considered in this study. This study utilised a positivist approach, focusing on the truth found in respondents by observing and recording the impact of fundamental laboratory skills on the students' actual academic achievement in the Rutsiro district of Rwanda through closed-ended questions.

### *Targeted Population*

There were 186 senior five (S5) students with Advanced levels from two secondary schools in Rwanda's Rutsiro district as the study's population.

### *Sample Size*

In this study, 80 students from two secondary schools participated, with 20 selected in combination with MCB (Mathematics, Chemistry, and Biology) and 20 selected in combination with PCB (Physics, Chemistry, and Biology). Purposive sampling was used, with five senior chemistry students chosen based on their participation and knowledge of fundamental chemistry laboratory skills. The sample size was determined using Sloven's formula (1), with 186 students, 62% girls and 38% boys, included in the study. Sloven's formula was utilised to determine the sample size from the population using an 8.5% margin of error and a confidence interval of 95%. The formula used was:

$$n = \frac{N}{(1 + N \times e^2)} \quad (1)$$

where: N = population size, n = sample size, e = margin error.

The detailed information of the sample is shown in table 1.

**Table 1:** Summary of information about participants in this study

| Secondary schools | Options | Lab materials equipped | Learners |
|---|---|---|---|
| School A | PCB | Not | 20 |
| | MCB | Not | 20 |
| School B | MCB | Yes | 20 |
| | PCB | Yes | 20 |
| Overall = 2 | 2 | | 80 |

*Methods and Procedures for Gathering Data*

*Data collection tools*

This study used a questionnaire and a practical test to gather data for research in 12 YBE without a lab but equipped with chemistry kits, as well as in a boarding school with a lab. Three sections (A, B, and C) were used to gather research data in order to address these research questions. The purpose of Sections A and B was to determine how fundamental laboratory skills changed over time among senior five students studying in two different secondary schools who were advanced learners pursuing chemistry as a major subject in schools with substantial chemistry labs and schools without such labs. Section C concerns the practical test of chemistry. The questionnaire items are shown in Table 2.

The questionnaire in Table 2 was designed to find out the development of fundamental laboratory abilities in chemistry among advanced learners and their impact on the academic achievement of S5 students in chemistry in Rutsiro. The students' questionnaire had more questions in section B, which evaluates basic chemistry laboratory skills, than sections A and C. It covered the personal data of the respondents and applied a five-scale rating developed by Likert, requiring respondents to respond according to how they agreed or disagreed with the state therein. Depending on how much the respondent agrees or disagrees with the statement, codes 1, 2, 3, 4, and 5 correspond to strongly disagree, disagree, undecided or not sure, agree, and strongly agree, respectively.

The 43 questions in three sections (A, B, and C) of this questionnaire on the table 2 were used to analyse and interpret the data. Section A connects theoretical lessons with practical and consists of 10 questions; Section B assesses essential skills in chemistry laboratory settings with 19 questions; and Section C offers a 14-question practical test in chemistry.

**Table 2:** Questionnaire items for students' development of fundamental laboratory skills.

| Statement | Strongly Disagree 1 | Disagree 2 | Undecided (Not sure) 3 | Agree 4 | Strongly Agree 5 |
|---|---|---|---|---|---|
| **SECTION A: Connecting theory and practice in chemistry** | | | | | |
| 1. I enjoy studying chemistry in practice as my major subject. | **1** | **2** | **3** | **4** | **5** |
| 2. Chemistry inspires and engages me constantly as an experimental science. | **1** | **2** | **3** | **4** | **5** |
| 3. One of my most enjoyable and fascinating activities is performing practical laboratory chemistry. | **1** | **2** | **3** | **4** | **5** |
| 4. I enjoy taking chemistry chapters that involve lab work. | **1** | **2** | **3** | **4** | **5** |
| 5. I am aware of the principles when working in the chemistry lab. | **1** | **2** | **3** | **4** | **5** |
| 6.Practices of chemistry improve my academic achievement. | **1** | **2** | **3** | **4** | **5** |
| 7. I find that the extraction method for isolating chemicals from plant sources is one of the most significant chemistry lab procedures. | **1** | **2** | **3** | **4** | **5** |
| 8. I am interested in studying organic chemistry laboratory procedures since they use the distillation process to separate the components of liquid mixtures. | **1** | **2** | **3** | **4** | **5** |
| 9. My favourite and most fascinating lab chemistry exercise is the melting point practical since it allows me to compare which crystals melt more quickly than others. | **1** | **2** | **3** | **4** | **5** |
| 10. My understanding of the chemistry subject has improved as a result of the laboratory work. | **1** | **2** | **3** | **4** | **5** |
| **SECTION B: Assessing fundamental laboratory abilities in chemistry** | | | | | |
| 1. I enjoy doing experiments in chemistry. | **1** | **2** | **3** | **4** | **5** |
| 2. I can measure the volume of liquid in the chemistry lab by using a burette. | **1** | **2** | **3** | **4** | **5** |
| 3. I'm certain that I can't measure a substance's mass in a lab using an analytical balance. | **1** | **2** | **3** | **4** | **5** |
| 4. Using a dropper is a simple task for me in the laboratory. | **1** | **2** | **3** | **4** | **5** |
| 5. I know how to use a pipette to transfer a tiny amount of liquid. | **1** | **2** | **3** | **4** | **5** |
| 6. During titration, I am aware that a beaker may hold the required volume of solution. | **1** | **2** | **3** | **4** | **5** |
| 7. I can prepare a copper (II) hydroxide solution in a test tube. | **1** | **2** | **3** | **4** | **5** |
| 8. Since I can use my hand to hold the heated test tubes, I cannot use a test tube holder. | **1** | **2** | **3** | **4** | **5** |
| 9. I'm not sure how to use a funnel and filter paper simultaneously during an experiment. | **1** | **2** | **3** | **4** | **5** |
| 10. Using a scoopula or my hands, if I'm wearing gloves, I can reach a certain solute concentration. | **1** | **2** | **3** | **4** | **5** |
| 11. A tripod stand can hold a beaker of wire gauze for support while it heats up. | **1** | **2** | **3** | **4** | **5** |
| 12. Lab experiments in chemistry aid in a thorough comprehension of the subject. | **1** | **2** | **3** | **4** | **5** |
| 13. I find it simple to operate the lab instrument known as a micropipette, which is used to precisely and accurately transfer liquid in the microliter range. | **1** | **2** | **3** | **4** | **5** |
| 14. You cannot store numerous sets of test tubes in a test tube rack in a laboratory. | **1** | **2** | 3 | **4** | **5** |

| | | | | | |
|---|---|---|---|---|---|
| 15. A test tube rack may accommodate several sets of test tubes at once. | **1** | **2** | 3 | **4** | **5** |
| 16. To handle various materials at high temperatures, such as picking up flasks, beakers, and test tubes, crucible tongs are essential. | **1** | **2** | 3 | **4** | **5** |
| 17. You can carry a beaker around without it coming into contact with your hands by using beaker tongs. | **1** | **2** | 3 | **4** | **5** |
| 18. I'm positive that high boiling, low flammability liquids aren't heated quickly with Bunsen burners. | **1** | **2** | 3 | **4** | **5** |
| 19. I find it hard to defend the use of a ring stand as a piece of equipment in a laboratory. | **1** | **2** | 3 | **4** | **5** |
| **SECTION C: Chemistry practical test** | For every question below, highlight the letter that corresponds to the right response. | | | | |
| 1. The following equipment is required when measuring 5 grams of sodium chloride: | (a)weighing balance | (b) spoon | (c) beaker | (d) holder for test tubes | |
| 2. Which procedures/methods must you adhere to while creating a standard solution? | (a) dilution method | (b) analytical method | (c) weighing method only | (d) both the procedure of diluting and weighing | |
| 3.The substance silver chloride is... | (a) blue | (b) green | (c) white | (d) yellow | |
| 4.Solution A has a PH centre of 3 | (a) solution A is a strong base | (b) It is not an acid solution | (c) solution A is a weak base | (d) Solution A is a strong acid | |
| 5.The litmus paper is defined as: | (a) paper that remains unchanged when material is added | (b) the litmus paper serves as a display for the PH range of a scale. | (c) the material used to determine whether a substance is basic or acidic is known as a litmus paper. | (d) the litmus paper cannot distinguish between an acidic and a basic solution | |
| 6.The gases sulphur dioxide and carbon dioxide are... | (a) the oxides of bases | (b) the acidic oxides | (c) the oxides that are neutral | (d) are both included in amphoteric oxides | |
| 7. One kind of indicator that can be utilised to titrate strong bases and weak acids is... | (a) whichever indicator | (b) phenolphthalein | c) the indicator called methyl orange | d) there isn't a good indicator provided | |
| 8. The following represents the molarity of the solution of substances: | (a) mass of the solvent relative to the mass of the malar | (b) molar mass of the solute | (c) ratio of solute mole to solution volume | (d) moles of solution relative to the entire solution volume | |
| 9.The end point in titration means... | (a) the stage at which the indication changes colour | (b) the point at which the colour indicator stays the same | (c) the point where amount of titrant is enough to complete neutralisation | (d) the point at which the titrant's concentration is sufficient to completely neutralise | |
| 10.A titration experiment may be used to... | (a) finding the equivalent position | (b) figuring out the sample's concentration | (c) only the volume of the unidentified concentration | (d) the true responses are a and b. | |

| | | | | |
|---|---|---|---|---|
| 11. What is the term for the electrolysis negative electrode? | (a) the electrode of the cathode | (b) the electrode of anode | (c) the electrolyte | (d) the electrolytic cell |
| 12.Electrolytes have the ability to conduct electricity by... | (a) electron movement from the anode to the cathode | (b) electrons moving from the cathode to the anode | (c) the answers are a and b. | (d) movement of atoms |
| 13. Among these substances, which one is not an electrolyte? | (a) the diluted sulphury acid | (b) potassium bromide solution | (d) the element known as silver | (e) the diluted hydrochloric acid |
| 14. Regarding the production of sodium chloride through direct interaction of sodium and chlorine, which statement is accurate? | (a) the reducing agent is sodium | (b) chlorine is reduced | (c) the reduced is sodium, and reducing agent is chlorine | (d) an oxidising agent is sodium, and the reduced substance is chlorine |

*Validity and Reliability of the study*

The questionnaire underwent review by education specialists, was revised, and was approved by a supervisor to ensure its validity and assess the relationship between questions and objectives.

The University of Rwanda's Department of Chemistry Education confirmed the construct validity and content of an instrument. A pilot study was conducted, determining the questionnaire's reliability coefficient using Cronbach's alpha.

*Data analysis*

The purpose of the one-sample t-test is to ascertain whether there is a statistically significant difference between the means of two different samples. Therefore, it was used to investigate the attitude mean difference scores between school A and school B.

When comparing the two groups, it is sufficiently evident that there is a significant difference in the mean between the schools and the students' test scores to the paired t-test, indicating that the mean difference between the schools (MD = 1.463) is greater than the mean difference between the tests (MD = 1.363). The results of the analysis show that, at the 0.001 level of significance, there is a statistically significant difference in the scores for the two means ($t(79) = 0.000$, $n = 80$, $P < 0.001$). The result of the t-test found that there is a significant difference between school A and school B.

## Results and Discussion

*Recording of fundamental laboratory skills in chemistry for students in secondary education*

Table 3 below provides information on respondents' proficiency with fundamental laboratory techniques in chemistry in both secondary schools in Rutsiro district.

**Table 3:** Students' fundamental laboratory skills in chemistry at School A and School B

| Combinations | PCB, MCB | |
|---|---|---|
| | Learners having a sufficient background in chemistry lab | Inadequately skilled learners in basic chemistry lab |
| Secondary school B | 27 to the 40 | 13 to the 40 |
| Secondary school A | 16 to the 40 | 24 to the 40 |

As basic experiments are necessary to teach students the contents of their core subject, the researcher learned a great deal about how the learners acquired this knowledge. The researcher concluded that without lab supplies, students were not able to understand chemistry. According to the results, chemistry classes did not give pupils the chance to work with materials. The goal of the study was to determine how advanced learners acquired fundamental laboratory skills in chemistry. Therefore, the learners asked the researchers to share all the knowledge to them. Their remarks were duly noted.

In this study, the term "chemistry laboratory basic skills" refers to the essential abilities and competencies required for any instructional context where students must eventually observe or work with the materials and objects under study. The author distinguishes this type of activity as "practical work" rather than "laboratory work" because it is not confined to a specific location. Although it may occur outside the classroom, such as at home or in the field, students can still observe or manipulate objects in a laboratory or educational institution.

Abdi (2014) reports that an eight-week study on 40 grade five students from two different classes selected by purposive sampling showed that students taught with inquiry-based learning performed better on tests than students taught with traditional methods. The majority of students (83.0% and 85.0%, respectively) agreed that the use of chemistry practical increases students' understanding of concepts and makes learning enjoyable, as further highlighted by Tahir Adamu Koki (2019) from Nigeria, who investigated the effect of chemistry practical on students' performance in the subject for 95 students and 113 teachers in 20 secondary schools.

This study focused on the three dimensions that serve as the basis for learning objectives related to student performance: academic competencies, cross-cutting concepts, the University of Rwanda Framework, and the CBC for Key Competencies for Lifelong Learning. Through our actions, we hope to prepare the students for lifelong learning (REB, 2015). Investigating and discussing the role of basic laboratory skills in chemistry in science education at the school level is another goal that this section considers (Efe & Abamba, 2023). Hence, this study examined the role of fundamental laboratory abilities in chemistry in the teaching and learning of science at the school level.

***Finding out the improvement of fundamental laboratory abilities in chemistry at both schools with and without a chemistry lab***

The goal of the study was to compare advanced students majoring in chemistry at schools with a chemistry lab to those without one in order to determine how their fundamental laboratory skills were developing. The research employed 29 closed-ended questions to gather information on the fundamental chemistry laboratory skills developed by senior fifth-grade students. Two parts of the questionnaire were involved: Section A, which is concerned with connecting theory and practice in chemistry, and Section B, which is related to assessing fundamental laboratory abilities in chemistry.

Table 4 below was used to describe the differences in terms of statistics between the two groups toward the fundamental laboratory skills.

**Table 4:** Comparison of mean data of School A and School B

| | Mean | SD |
|---|---|---|
| School A | 19.98 | 2.769 |
| School B | 21.83 | 1.973 |

According to the data above, there was a comparable difference between the mean score for schools B (M = 21.83, SD = 1.973) and A (M = 19.98, SD = 2.769). It was evident from the analysis of the data that School B's mean score was generally higher than that of school A, indicating a notable improvement in academic performance and a noticeable increase in fundamental laboratory practical skills.

Based on **the improvement of fundamental laboratory abilities in chemistry at both schools with and without a chemistry lab,** advanced learners are pursuing core subjects such as chemistry in their studies. Students studying chemistry can benefit from the experiences provided during practical.

For over a century, practical work has played a pivotal and unique role in the education of chemistry, spreading from elementary school to higher education (Koller et al., 2015). A fundamental aspect of chemistry as a core subject in schools is that students must engage in laboratory work in order to acquire the necessary knowledge in the subject. (Shana & Abulibdeh, 2020).

The ability to do specific lab operations is what Salin (2012) defines as basic laboratory abilities in chemistry. In order to perform well in advanced secondary school chemistry, students must be able to use a burette, create a standard solution, weigh with an analytical balance, use a dropper, heat using a hot plate or heating mantle, use beakers, measure volumes, use test tubes, use test tube holders, peak powder of solids, and filter.

*Evaluating performance in relation to a chemistry practical test*

This study was involved in evaluating performance in relation to a chemistry practical test. Section C of the questionnaire was used to evaluate students' performance on a chemistry practical test in order to ascertain how much both schools had improved their chemistry instruction. This section was regarded as a chemistry practical test. To determine whether there is a statistically significant difference between the means of two distinct samples, the one-sample T-test was used. Consequently, School A's and School B's attitude mean difference scores of the two groups were analysed using it. When comparing the practical test scores obtained from the questionnaire, there was a noticeable variation in the means. The results of the paired t-test show that the test mean difference (MD = 1.363) is less than the school mean difference (MD = 1.436). The analysis's findings also demonstrated a statistically significant difference in the scores for the two means at the 0.001 level of significance ($t(79) = 0.000$, $n = 80$, $P < 0.001$). According to the t-test results, School A and School B differ significantly from one another in the chemistry practical test.

The data is interpreted in Table 5 below to evaluate the performance of students taking chemistry in secondary schools as the core subject in the practical test.

**Table 5:** Analysing the results of two secondary schools with one sample test.

| Schools | df | Sig.(2-tailed) | Mean difference |
|---|---|---|---|
| | 79 | .000 | 1.436 |
| Test marks | 79 | .000 | 1.363 |

The statistical data indicates that there is a correlation between students' academic accomplishment and their mastery of fundamental chemistry practical abilities, as shown in table 5. The statistical findings from comparing the two groups towards the practical test in chemistry show that students from School B, which has a well-equipped lab, passed 85% and failed 15%, while students in School A, which has no well-equipped lab but has chemistry kits, passed with 42.50% and failed with 57.50%, as shown in Figure 1.

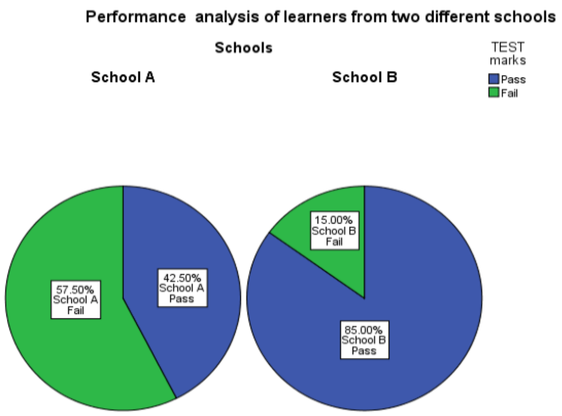


**Figure 1:** Comparison of students' achievement on a practical chemistry test between School A and School B

The contrasting performance of learners on a chemistry test of practical indicates the impact of basic skills developed on academic performance, allowing for determination of their success**.**

The major goals of teaching science, and chemistry in particular, are to help students become engaged, feel committed and self-assured, acquire scientific literacy, and have a positive attitude towards science. When students are in a well-equipped laboratory, they perform better on average and have a more positive attitude towards chemistry than when they are in an inadequately equipped laboratory (Iyamuremye et al., 2023).

The practical chemistry test results show that schools A and B differ significantly from one another. Both the experimental and control groups showed improvements. However, the experimental group's attitude had changed more than the control groups in terms of chemistry. $P < 0.001$ in the one-sample t-test results thus demonstrated their statistical significance. The results of this study revealed that students' grades in practical chemistry at both secondary schools A and B differ significantly from one another. (Okafor, 2021). Practical work enhances motivation and a positive mindset, therefore improving learning and increasing students' achievements in chemistry.

## Conclusion

Based on the findings, this study concluded and detected that learning chemistry was more enjoyable and comprehension was improved with practical. As a result, it also supports students in applying what they have learned in class to real-world situations, particularly in chemistry, and encourages them to conduct in-depth research, all of which have an impact on their academic achievement.

The study concluded that fundamental laboratory skills improved students' performance in chemistry. This study highlights the importance of motivation and an optimistic outlook in enhancing learning and raising students' achievement levels. Teaching science, particularly chemistry, aims to help students become engaged, feel committed, acquire scientific literacy, and have a positive attitude towards science. A well-equipped laboratory leads to better performance and a more positive attitude towards chemistry.

Furthermore, this study concluded that chemistry attitudes significantly influenced students' views towards learning in general and science in particular. Over and above that, this study evaluated the impact of practical chemistry laboratory skills on students' performance. It suggests adding hands-on activities to pique students' interests and encourage chemistry.

**Recommendations**

Based on its findings, the study suggests the following: By engaging in practical work, students can sustain their positive interest in science. To ensure that students' learning and academic performance continue to improve, teachers should stick to teaching science through the laboratory method. Principals should keep creating a supportive laboratory environment in their schools so that educators and students can keep pushing for better teaching and learning, learning objectives, and academic success in science education. For their laboratory classes, science teachers instructing in chemistry should have preparation time to gather supplies and equipment.

**Implications of the Research Results**

The study's findings can benefit various stakeholders in education, including students, instructors, planners, auditors, instructors, and chemistry officials. It raises awareness about the challenges faced by advanced chemistry students and draws attention to problem-solving strategies. The findings support the practical approach of chemistry teachers, allowing training facilities to focus on fundamental laboratory skills. It may also aid school inspectors in modifying their inspection methodology to better assess the practical and skill acquisition processes.

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# Learning Materials Utilising Sustainability Pedagogy in Grade 8 Ecology

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## Abstract

*Science education in the Philippines is anchored on the United Nations (UN) goals on sustainability education, as provided in K to 12 Science Curriculum, which envisions learners to be environmentally literate, critical problem solvers, and responsible stewards of nature. However, K to 12 implementations in the Philippines faced several challenges that resulted in student's poor awareness and knowledge about Philippine wildlife and conservation, as well as low proficiency in science. In order to enhance the proficiency and competence of students in ecology, learning materials utilising sustainability pedagogy were developed. A Descriptive-developmental research method was used to evaluate the developed learning materials (DLMs) and describe the experiences of students in the DLMs. A Four-Point Likert Scale technique was employed to evaluate the DLMs. structured journaling and thematic analysis were used to determine the experiences of students in using the DLMs in ecology. The experts' evaluation showed that the five DLMs utilising sustainability pedagogy in grade 8 ecology passed the criteria of DepEd (Department of Education) as stipulated in the Learning Resources Management and Development System (LRMDS). Introduced features, sustainability-themed, issue-based, contextualised, and reflective likewise obtained very satisfactory result. Students found the DLMs interesting, comprehensible, promote awareness, relevant to the community's environmental issues, and helped them to express their opinions. The study recommended that the valid and modified DLMs utilising sustainability pedagogy may be used by biology teachers in their lessons, can still be improved and further contextualised as well as used in other topics in ecology and environmental science.*

**Keywords:** Science education; Sustainability pedagogy; DLMs; Thematic analysis; Ecology

## Introduction

Science education in the Philippines is anchored on the UN goals on sustainability education, as provided in K to 12 Science Curriculum Guide (DepEd, 2016; SEI-DOST & UP NISMED, 2011), which envisions learners to be environmentally literate, to the extent as critical problem solvers and responsible stewards of nature. The UN Sustainable Development Goals (SDGs) related to environmental literacy include clean water and sanitation, climate action, life below water, and life on land. These goals are incorporated in one of the core topics in the science curriculum, particularly in ecology, making environmental and ecological literacy significant variables to measure proficiency in science. Environmental conservation and ecological balance are also enshrined in Republic Act 9512, known as National Environmental Awareness and Education Act of 2008, which directs the Department of Education to integrate environmental education into the curricula at all levels. Additionally, Republic Act 9729, or the Climate Change Act of 2009, was also designed to fulfil human needs while preserving the quality of the natural environment for current and future generations.

However, challenges in science education resulted in student's insufficient understanding and awareness of environmental science and ecology (Panjaitan et al., 2021). One of these is the insufficiency of teaching materials and resources that will help to facilitate and promote the teaching and learning process (Visconde, 2015; Penalba & Janer, 2019). Sufficient teaching materials and resources need to be coupled with the quality and appropriateness of teaching and learning materials. Dizon et al. (2019) argued that instructional materials must be enhanced to make sure that the learning process is supported among students in the current curriculum.

Filipino students have poor awareness and knowledge about Philippine wildlife and conservation (Gamalo et al., 2018). Knowledge about species conservation is one of the important concepts in ecology and environmental literacy, and one of the predictors in measuring scientific literacy. The Programme for International Student Assessment (PISA) measures scientific literacy based on the use of scientific knowledge to identify questions, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions about science-related issues. These science-related issues include ecological issues such as species extinction. According to the PISA results in 2018, almost no student in the Philippines attained level five or six proficiency in science, who can creatively and autonomously apply their knowledge of and about science to a wide variety of situations. This lack of proficiency is also reflected in the results of the National Achievement Test administered to secondary learners in 2015, which revealed a mean percentage score of 57.11% in science, far below the target passing rate of 75% (Logmao, 2019). In the context of the study locale, as reflected in students' written works on ecology modules, grade 8 students got an average rating of 67.45%, which indicates poor understanding and appreciation of ecological concepts.

Hence, improving student's awareness, attitudes, beliefs, and behaviours is significant and necessary through the further integration of environmental and ecological education (Reyes, 2014; Schleicher, 1989; Howard, 2000). Ecological and environmental education should be holistic through learning activities that are reflective and integrative to hone students to be responsible stewards of nature (Ardoin and Heimlich, 2021). Thus, this study focused on developing supplementary learning materials in ecology, as according to Arga and Rahayu (2019), environment-based learning resources improved the eco-literacy of students. The study utilised sustainability pedagogy in developed learning materials in ecology, specifically covering (1) species, (2) species diversity, (3) energy in an ecosystem, (4) matter in an ecosystem, and (5) ecological footprint.

Sustainability pedagogy incorporates issue-based learning, sustainability-themed approach, contextualized, and reflective learning. Issue-based learning was used in this study as Ke et al. (2020) found out that issue-based learning work to be relevant, interesting, promoting agency, and beneficial for their science learning. Issue-based learning also has been found to improve students' learning outcomes both in the aspect of mastery of concepts and problem-solving skills (Kamaludin et al., 2018). Sustainability-themed approach was based on the study Burns (2013) that increases learners' systemic/thematic understanding of the relationships between complex sustainability issues. Contextualized feature was used as it caters to reflection and relational understanding of sustainability issues in different areas, thus, students find personal meaning and relevance in learning locally (Singleton, 2015). Lastly, reflective learning was used as it has been showed that conceptual understanding, critical thinking, and problem-solving skills significantly improved with its use.

The study developed learning materials using sustainability pedagogy, an approach that incorporates sustainability themes, real-world ecological issues, local settings, and reflective activities, to enhance the competence of students in ecology. Specifically, it sought to answer the following research questions:

1. How can sustainability pedagogy be applied to develop learning materials in ecology with the following features: (a) issue-based, (b) sustainability-based, (c) contextualized, and (d) reflective?
2. What are the expert's evaluations on the developed learning materials in ecology in terms of: (a) content, (b) format, (c) presentation and organisation, (d) accuracy and up-to-date information, and (e) features of the developed learning materials?
3. What are the student's experiences in using the developed learning materials on ecology utilising sustainability pedagogy? and

What modifications may be done to improve the learning materials based on: (a) students' experiences, (b) expert's evaluations?

**Methodology**

Developmental research design was used in this study. Developmental research is a systematic study of designing, developing, and evaluating instructional products that meets internal consistency and effectiveness criteria (Richey, 1994). This approach offers researchers the chance to answer the research questions.

**Instrument**

The study used an Evaluation Tool on the Developed Learning Materials, an adapted four-point Likert scale evaluation tool aimed to determine the validity and presence of features of sustainability pedagogy in the developed learning materials. This tool was adopted to the DepEd's LRMDS for the evaluation of print resources (DepEd, 2016), and added researcher-made criteria and indicators to evaluate the validity and presence of features of the developed learning materials. Experts evaluated the developed learning activities based on content, format, presentation and organisation, accuracy and up-to-date information, and features of the developed learning materials. The reliability of the instrument gained a Cronbach's alpha of 0.99.

Researcher-made Journal Guide Questions were used to determine the experiences of students when performing each of the developed learning activities. The journal determined the interests, realisations, clarifications, and proposed modifications of students in the developed learning activities. The reliability of the instrument obtained a Cronbach's alpha of 0.94.

**Sample**

Thirty-eight (38) purposively selected Grade 8 students of Sorsogon National High School were the respondents in this study. Sorsogon National High School was chosen as the ecological issues that will be used in the learning materials is contextualized in Sorsogon and it represented the various characteristics of different public schools in the country, especially in terms of curricular offerings. Grade 8 students were selected because Biology subjects, especially ecology competencies, are offered in the fourth quarter. In addition, students were already grouped into sections prior to its implementation that made the conduct of the study more natural and less obtrusive since the students' groupings will remain the same. Furthermore, the study needs heterogeneously grouped students with interest in learning biology to gather more responses in the pilot test of the developed learning materials as it will include reflective activities.

Ten (10) purposively selected pool of experts evaluated the developed learning materials. Teacher respondents assessed the content, format, presentation and organisation, accuracy and up-to-date information, and features of the developed learning materials. Teacher respondents were selected based on two qualifications: (a) preferably holding master's degree in biology, science education, educational management, or any related fields, and (b) possessing three or more years of professional experience in teaching Biology or Science or working as an instructional or educational developer.

## Data Collection

### *Phase 1 – Design and Development.*

The researcher reviewed the grade 8 science module, specifically the topics of ecology located in the last part of the module to determine where to integrate the features, issues that were used related to the topic, and to identify other opportunities to enhance the module. DepEd orders and regional memorandum orders were also reviewed and utilised to support the integration of the features. Likewise, the most essential learning competencies adopted, considering the pandemic were reviewed and incorporated into the learning materials. The learning materials in ecology that were developed utilised sustainability pedagogy with features including sustainability-themed, issue-based, contextualized, and reflective. Specifically, the learning activity have parts such as: (a) core ecological issue, (b) learning objectives, (c) list of terminologies, (d) sustainability focus (e) contextualized ecological issue (f) practice task 1, (g) practice task 2, (h) practice task 3, (i) reflection (j) rubric (if necessary), (k) references.

### *Phase 2 – Evaluation*.

The Experts' evaluation sheet was used to evaluate the developed learning materials utilising sustainability pedagogy. The experts evaluated the developed learning materials based on content, format, presentation and organisation, accuracy and up-to-date information, and features.

### *Phase 3 – Implementation*.

The aim of the pilot testing was to gather the response and experiences of students in performing the activity which served as the basis for the modifications of the introduced learning materials. Each learning material was answered by students in a span of one week due to the current educational system, it was collected and analysed every week until all learning materials were done. After that, journal guide questions were distributed to capture the experiences of students in answering and performing the developed learning activities in ecology utilising sustainability pedagogy. Finally, focus group discussion was administered for a post implementation interview of the study to student-respondents through Google meet calling.

### *Phase 4 – Modification*.

Learning materials were modified based on the responses of students in journal and experts' comments and suggestions. Further, learning materials were modified, which may be replacement, removal, or addition of concepts or any parts in the learning materials.

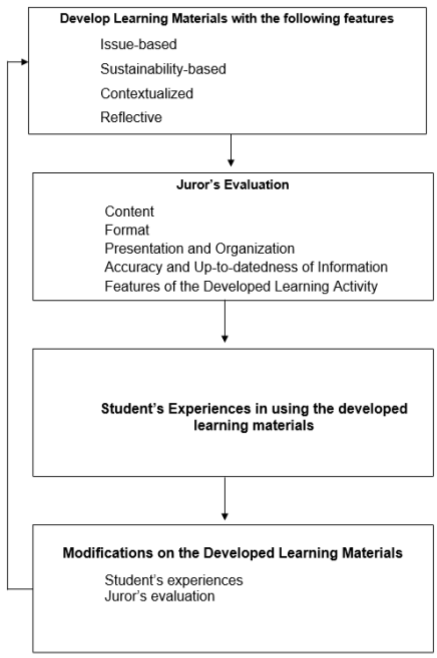
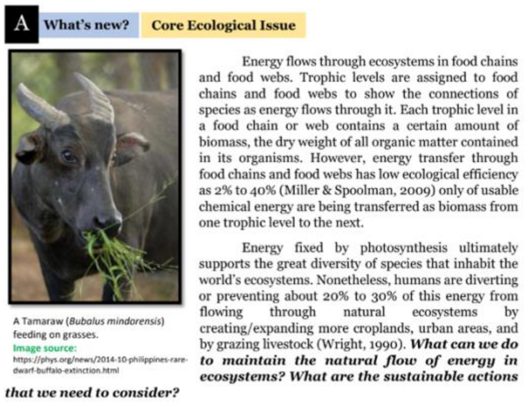



**Figure 1.** Summary of data collection procedure.

## Results and Discussion

### *Learning Materials Utilising Sustainability Pedagogy*

Learning materials utilising sustainability pedagogy were developed based on the DepEd Regional Memorandum No. 51, Series of 2020, which includes a learning activity sheet sample and suggested template. However, a notable difference between the DepEd format and the format of the developed learning materials in ecology is the inclusion of the introduced features, that is, the core ecological issue, suggested sustainable actions, contextualised ecological issue, and reflection.


A What's new? Core Ecological Issue

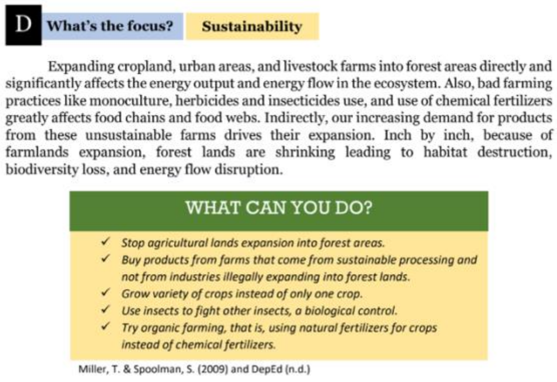
Energy flows through ecosystems in food chains and food webs. Trophic levels are assigned to food chains and food webs to show the connections of species as energy flows through it. Each trophic level in a food chain or web contains a certain amount of biomass, the dry weight of all organic matter contained in its organisms. However, energy transfer through food chains and food webs has low ecological efficiency as 2% to 40% (Miller & Spoolman, 2009) only of usable chemical energy are being transferred as biomass from one trophic level to the next.

Energy fixed by photosynthesis ultimately supports the great diversity of species that inhabit the world's ecosystems. Nonetheless, humans are diverting or preventing about 20% to 30% of this energy from flowing through natural ecosystems by creating/expanding more croplands, urban areas, and by grazing livestock (Wright, 1990). ***What can we do to maintain the natural flow of energy in ecosystems? What are the sustainable actions that we need to consider?***

A Tamaraw (*Bubalus mindorensis*) feeding on grasses.
Image source:
https://phys.org/news/2014-10-philippines-rare-dwarf-buffalo-extinction.html

**Figure 2.** Excerpt from the developed learning material 1, showing the issue-based feature.

Figure 2 shows the first feature that was utilised in the developed learning materials. It was issuing based learning where it uses ecological issues to stress out the need to study ecology, to justify the importance of protecting species, biodiversity, ecosystems, and personal behaviours relative to the environment and to get students' interests in the learning materials. The inclusion of this feature to the developed learning material is based on the study that problems in the environment have a correlation to the biological concepts, especially, ecology, conservation, and extinction issues (Presley et al., 2013). According to the result of the study of Kamaludin et al. (2018), issue-based teaching materials has been proven to improve students' learning outcomes. Improved students' learning outcomes happens as students will be engaged to learn if the source of learning is a phenomenon or issue in their environment (Elder, 2015).


D What's the focus? Sustainability

Expanding cropland, urban areas, and livestock farms into forest areas directly and significantly affects the energy output and energy flow in the ecosystem. Also, bad farming practices like monoculture, herbicides and insecticides use, and use of chemical fertilizers greatly affects food chains and food webs. Indirectly, our increasing demand for products from these unsustainable farms drives their expansion. Inch by inch, because of farmlands expansion, forest lands are shrinking leading to habitat destruction, biodiversity loss, and energy flow disruption.

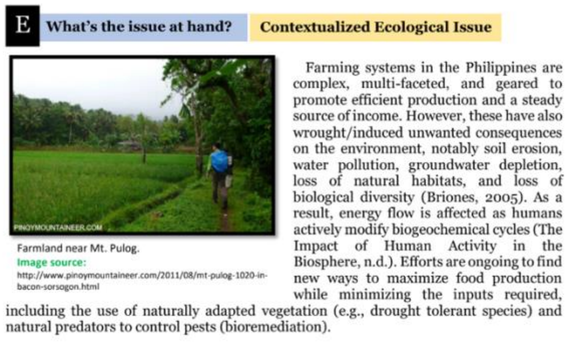
WHAT CAN YOU DO?

- ✓ *Stop agricultural lands expansion into forest areas.*
- ✓ *Buy products from farms that come from sustainable processing and not from industries illegally expanding into forest lands.*
- ✓ *Grow variety of crops instead of only one crop.*
- ✓ *Use insects to fight other insects, a biological control.*
- ✓ *Try organic farming, that is, using natural fertilizers for crops instead of chemical fertilizers.*

Miller, T. & Spoolman, S. (2009) and DepEd (n.d.)

**Figure 3.** Excerpt from the developed learning material 1, showing the sustainability-themed feature.

The sustainability-themed feature show in figure 3, provided students with ideas on what they can do to change their practices towards sustainability that aims to protect the ecosystem and the biodiversity. It encourages students to conserve and protect biodiversity through simple changes in actions, such as buying products from farms that employ sustainable processing, which could have a great impact in the environment. Buying and consuming sustainably produced products shows care for the environment (Wojciechowska-Solis & Barska, 2021). A Sustainability-themed approach promotes the development of the knowledge, skills, understanding, values, and actions needed to make a sustainable community (Laurie et al., 2016). Similarly, it increases a learner's systemic understanding, enhances civic responsibility, and creates transformative learning experiences (Burns, 2011).


E What's the issue at hand? Contextualized Ecological Issue

Farming systems in the Philippines are complex, multi-faceted, and geared to promote efficient production and a steady source of income. However, these have also wrought/induced unwanted consequences on the environment, notably soil erosion, water pollution, groundwater depletion, loss of natural habitats, and loss of biological diversity (Briones, 2005). As a result, energy flow is affected as humans actively modify biogeochemical cycles (The Impact of Human Activity in the Biosphere, n.d.). Efforts are ongoing to find new ways to maximize food production while minimizing the inputs required, including the use of naturally adapted vegetation (e.g., drought tolerant species) and natural predators to control pests (bioremediation).

Farmland near Mt. Pulog.
Image source:
http://www.pinoymountaineer.com/2011/08/mt-pulog-1020-in-bacon-sorsogon.html

**Figure 4.** Excerpt from the developed learning material 1, showing the contextualized ecological issue feature.

The developed learning materials presented ecological issues that have occurred or reported locally, presented issues in the community that induce social and environmental engagement among students, as well as use illustrations/images that are taken or can be observed locally which makes competencies meaningful, relevant, and useful to all learners. The appearance of this feature is displayed in figure 4. Contextualized learning caters meaningful learning in such a way that the content makes sense to student on their own frames of reference, encouraging deeper reflection and a sense of belonging to create a holistic understanding of sustainability (Singleton, 2015; Woodhouse & Knapp, 2000).

The last feature introduced is reflective which enables students to reflect on their own current actions, practice self-assessment, provide them the opportunity to change their actions and values towards sustainability, and encourage them to speak up on the ecological issues presented, as shown in Figure 5. The five developed learning materials include questions on students' realisation after answering the learning activities. Reflective learning was proved to be an effective means of developing student's environmental sensitivity and decision-making skills (Guerrero, 2017).

***Expert's Evaluation on the Developed Learning Materials***

The five developed learning materials obtained passing rates in all criteria, including content, format, presentation and organisation, and accuracy and up-to-date information, as stipulated in the DepEd Guidelines and Processes for LRMDS Assessment and Evaluation (DepEd, 2016).

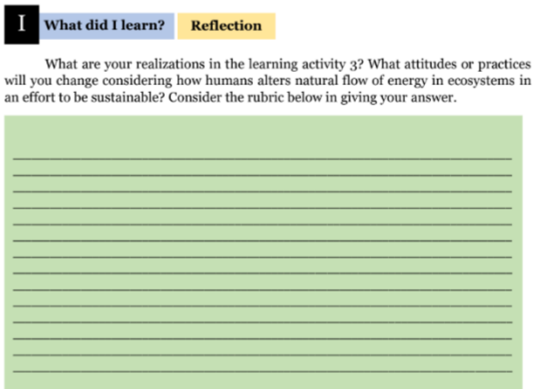



**Figure 5.** Excerpt from the developed learning material 1, showing the reflective feature.

**Table 1**. Summary of Experts' Evaluation on the Developed Learning Materials Utilising Sustainability Pedagogy

| Criteria | Points to pass (DepEd, 2009) | LM1[a] | LM2 | LM3 | LM4 | LM5 | Over-all Rating |
|---|---|---|---|---|---|---|---|
| Content | At least 21 of 28 | 26.5 | 27.5 | 27.3 | 27.4 | 27.4 | 27.22 |
| Format | At least 54 of 72 | 68.4 | 70.7 | 70 | 67.8 | 71.9 | 69.76 |
| Presentation and Organisation | At least 15 of 20 | 18.5 | 19.1 | 19.4 | 19.2 | 20 | 19.24 |
| Accuracy and Up-to-date Information | At least 18 of 24 | 23 | 23.4 | 23.2 | 23.4 | 23.7 | 23.34 |

Note: [a]Learning Materials

***Content***. Notably, in terms of content, LM1 to LM5 are excellent in terms of materials having free from ideological, cultural, racial, religious, and gender biases as well as prejudices (mean = 3.96). The findings suggests that the content of the developed learning materials is fairly presented relative to social and cultural norms, resulting in the students to have a positive outlook towards the developed learning materials and gaining learners' interest (DepEd, 2016). As noted by the Council of Europe (2022), educators should recognize the need to develop in every person a tolerant, non-discriminatory attitude, and create a learning environment that acknowledges and benefits from diversity through the incorporation of intercultural learning into the learning materials. However, the relatively low rating on the suitability for students' level of development is transparent with the comments of the experts, which suggests a need, *define and distinguish the terms used in the learning materials (5), provide adequate and suitable discussion of concepts to properly scaffold the students (7), provide examples and further discussion of concepts (7).* These comments were used to clearly point out the concepts, guide students for better understanding, and be able to thoroughly discuss the concepts for students to learn meaningfully in the learning materials and to equip students with adequate concepts before they perform the activities.

***Format***. Regarding the format of the developed learning materials, the data suggests that the size of letters of the developed learning materials is appropriate to the intended user, spaces between letters and words facilitate readability, fonts are easy to read, and print quality is high (cumulative mean = 15.5). The data imply that the developed learning materials are attractive, simple, with adequate illustration in relation to text, and there is a harmonious blending of elements. As underlined by Marinelli et al. (2013), well-written and well-designed learning materials are an important predictor of student learning. As what Shanahan (2020) pointed out, reading instruction should intentionally place students in situations in which their understanding of a text will depend upon their ability to surmount some particular conceptual or linguistic barriers. Despite these findings, there is still a need to improve the format of the developed learning materials based on the comments of the experts. Experts suggested *bold and italicize appropriate words and phrases (8), indent sentences (4), and contextualize images used (7)*.

***Presentation and Organisation***. As to the presentation and organisation, the learning materials are very satisfactory in terms of length of sentences that are suited to the comprehension level of the target reader (mean = 3.9). The data indicates that the complexity of sentence patterns typically used is considered and simplified by omitting connections between ideas, which may reduce the user's ability to make meaning (DepEd, 2016). Similarly, the result of the study of Duncan et al. (2021) demonstrated that students use their understanding of sentences, for which they have gained a strong foundation through oral language to springboard into reading for understanding. Based on the comments of the jurors, there is still a need to *provide a brief introduction in all of the developed learning materials (2), sentences/concepts should be presented in a more positive* approach *(2), Give clear directions in the activity (8)*. These comments entail modifications of the developed learning materials to better present the concepts and activities.

***Accuracy and up to date of Information***. Finally, the accuracy and up-to-date information notably depict that the developed learning materials have no obsolete information (mean = 3.94). The rating on the accuracy and up-to-date information also indicates that the developed learning materials require slight improvements in the grammatical usage, as the jurors observe *minor grammatical errors (7)*.

**Table 2** Summary of Experts' Evaluation Relative to the Features of the Developed Learning Materials

| Criteria | LM1 | VI[a] | LM2 | VI | LM3 | VI | LM4 | VI | LM5 | VI | Overall mean | VI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Features of the Developed Learning Activity | | | | | | | | | | | | |
| Sustainability-themed | 3.85 | VS[b] | 3.98 | VS | 3.9 | VS | 4 | VS | 3.95 | VS | 3.94 | VS |
| Issue-based | 3.98 | VS | 3.95 | VS | 3.88 | VS | 3.9 | VS | 3.98 | VS | 3.94 | VS |
| Contextualized | 3.78 | VS | 3.93 | VS | 3.85 | VS | 3.78 | VS | 3.98 | VS | 3.86 | VS |
| Reflective | 3.9 | VS | 3.83 | VS | 3.95 | VS | 3.8 | VS | 3.95 | VS | 3.88 | VS |

Note: [a]Verbal Interpretation
[b]Very Satisfactory

Relative to *sustainability-themed*, a very satisfactory rating was obtained by the indicator, which states that the suggested sustainable actions are simple, doable, and relevant to the ecological issues (mean = 3.92). Suggested sustainable actions present what students can do to preserve and conserve biodiversity and their interactions. Similarly, according to UNESCO as reported by Leicht, A., Heiss, J., and Byun, W. J., (2018), the concept of teaching and learning must be transformed to enable individuals to lead sustainable development as agents of change. The inclusion of sustainability-themed is also convergent with the vision of the K to 12 curriculums to develop students to be environmentally literate and responsible stewards of nature (DepEd, 2016).

Regarding *issue-based* features, it can be inferred that the indicator, ecological issues/problems are evident in developed learning activities, obtained a very satisfactory rating (mean = 4). This means that the learning activity uses ecological issues that stimulate student's interest and promote critical thinking skills through questions. The ecological issue questions are clear and relevant to the ecological issue presented. Problem-based learning promotes critical thinking skills and creative thinking skills (Orozco and Yangco, 2016). In support of this, it could improve students' learning outcomes, both in the aspect of mastery of the concepts and problem-solving skills (Kamaludin, 2018). Hence, developing learning materials based on issues in students' environment will encourage them to explore ecological concepts.

Concerning to the *contextualisation* of the developed learning materials, ecological issues used in the learning activity that have occurred or reported locally are very satisfactory (mean = 3.88). The contextualised ecological issue makes competencies relevant, meaningful, and useful to all learners. According to the DepEd Order No. 32, s. 2015, the educational process should relate to a particular setting, situation, or application area to make the competencies relevant, meaningful, and useful to the learners. Contextualised learning (Singleton, 2015; & Woodhouse & Knapp, 2000), caters meaningful learning in such a way that it makes sense to them on their frames of reference, encourages deeper reflection and sense of belonging to create a holistic understanding of sustainability.

Finally, the developed learning materials are very satisfactory result relative to the *reflective* nature of the learning materials. The learning activity enables the students to reflect on their current actions. The learning activity allows learners to practice metacognition or self-assessment through reflection. This is supported by Guerrero (2017) who points out that reflective learning has proved to be an effective means of developing student's environmental sensitivity and decision-making skills. Furthermore, this is consistent with the conclusion of Oates (2014) that learning materials should guide learners to reflect on what they are learning.

Aside from the validity of the developed learning materials as evaluated by experts, the *inter-rater reliability of ratings* by the experts was also established. The experts on the five developed learning materials are very reliable with a mean Cronbach alpha of 0.91. This data suggests that the ratings the experts are in consonance to each other, consistent, and they agree on their assessment on different points, specifically, relative to the content, format, presentation and organisation, accuracy and up-to-date information, and features of the developed learning materials. The inter-rater reliability index of ratings by the experts further established the quality of the lessons, validity and fitness for classroom integration and implementation (Cajurao, 2019).

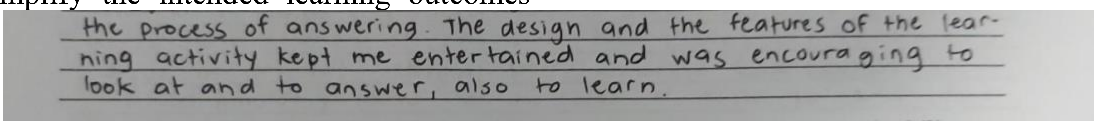
**Student's Experiences on the Developed Learning Materials**

The students found the DLMs interesting, comprehensible, promote awareness, relevant to community's environmental issues, and promote critical thinking.

**Table 3.** Summary of Students Experiences in the Developed Learning Materials.

| Theme | Experiences |
|---|---|
| Interesting | ● Students were entertained and encouraged to answer the developed learning materials.<br>● Interested in the topic and the activities.<br>● Become interested in the ecological issues introduced. |
| Comprehensible | ● Made their mind expand.<br>● Helped to understand species concepts.<br>● Don't need other devices to search for answers.<br>● Understood the basics of ecology and sustainability.<br>● Enabled the students to think critically. |
| Awareness | ● Become aware of the issues in the environment.<br>● Gained knowledge on how to maintain and care for the environment. |
| Relevance | ● Helped the students to connect with the present environmental condition in the community.<br>● Relate with what the students previously knew. |
| Express opinion | ● Analysed environmental issues in the community.<br>● Expressed opinions on different ecological issues presented. |

*Interesting/Encouraging*. Students showed positive responses in the learning activities suggesting their interest in the concepts and the design and features of the learning activities of the developed learning materials in ecology (Figure 6). Encouraging and interesting design of the learning activity enables the students to be engaged in and motivates them to demonstrate the objectives and competencies of the learning activity. When developing learning activities, it is important to consider the kinds of activities that students will need to engage in to exemplify the intended learning outcomes which would enable the students to practice the specific outcomes (The University of Queensland, 2022). In addition, the issue-based feature prompted and challenged the students to perform the learning activities in the developed learning materials. Issues presented in the developed learning materials keeps the students to ponder the causes, effects, and solutions of ecological issues.



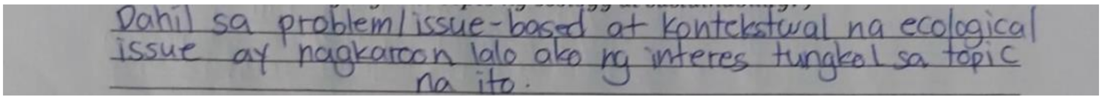



**Figure 6.** Sample students' journal entry saying learning activity was encouraging and interesting. (Translation: Because of the issue-based and contextualized ecological issue, I became in this topic.)

*Comprehensible*. The developed learning materials provided sufficient information per topic and comprehensively discussed the presented concepts, guiding the learners to understand the concepts well. Based on the journal entries, students say that *the learning materials helped me to understand species, ecology, and sustainability (10)*. Since the developed learning materials are designed to guide students in independent learning, with adequate discussion of concepts and issues, illustrations, and instructions, students easily understand and learn from the learning activities. This conforms with the idea of Kapur (2019) which explains that the availability of proper learning materials that educational institutions can render an effective contribution in achieving the desired educational objectives and promoting effective growth and development of students.

*Awareness*. Sustainability themed features of the developed learning materials made the students aware of their actions which are unsustainable and have an indirect negative effect on biodiversity and ecosystems (Figure 7). Learners' understanding and appreciation of the topic contributed to their awareness. Cheng, Yeh, Chao, Lin, and Chang (2020), concluded also that issue-based learning promotes students' knowledge and responsibility regarding environmental conservation.

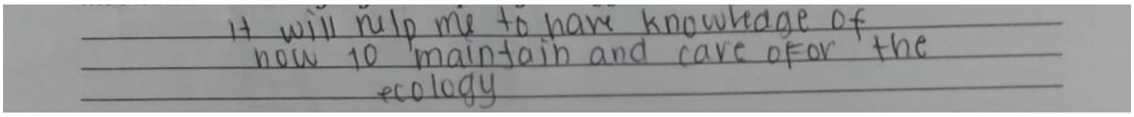



**Figure 7.** Sample student's journal entry showing that the learning activity helped the students to have knowledge on how to maintain and care for the environment. (*for the environment*)

*Relevance*. Students can relate and connect to the ecological issue presented and therefore learn meaningfully (Figure 8). In accordance with Sadler (2009), relevant issues help students increase their motivation to learn science and relate scientific content to their everyday lives. Similarly, the result of the study of González -Espada et al. (2014) showed that the contextualized activities improved the perception about science in many children.

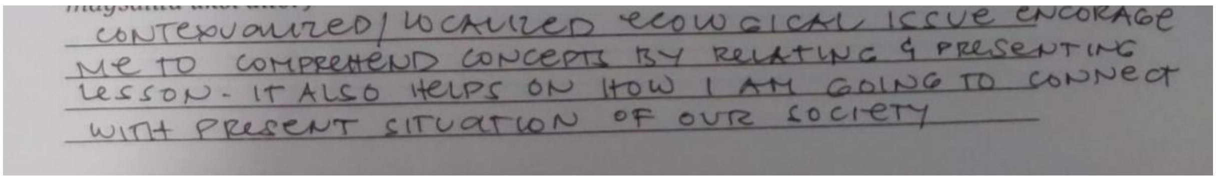



**Figure 8.** Sample student's journal entry showing that the learning material helped the students to connect with the present environmental condition in the community.

*Express opinion*. Through the reflective activity, students were able to express their opinion about ecological issues and address the challenge on how to protect and conserve biodiversity (Figure 9). The experiences of students are apparent in the findings of

Ashley et al. (2006) which suggested that reflection, on both process and content of learning, could help students move toward a deeper approach to learning. Similarly,

Colomer et al. (2020) found that reflective learning is likely to transform students' preconceived perspectives and social preferences to foster new reasoned action plans for decision-making and modify the students' beliefs, attitudes, and daily behaviour to develop competences that will ultimately result in promoting sustainability.

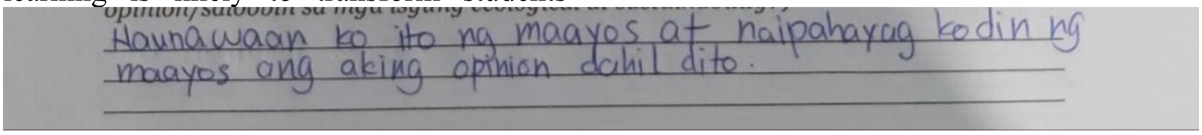



**Figure 9.** Sample student's journal entry showing that reflective activity helped to express learner's opinion on the issues. (*Translation: I understand it well and I expressed my opinions because of this.*)

**Modifications Based on Experts' Evaluation and Student's Experiences**

Comments, suggestions, and proposed modifications of the experts and the students were considered modifying of the developed learning materials. The developed learning materials need to be modified per area, i.e., introduction, objective, definition of terms, sustainability-themed, activity, and reflection. In developed learning activity 2, one of the suggestions of the experts, in terms of content, was to distinguish species diversity and biodiversity because they are used in the discussion. Distinguishing these two concepts would provide a more concrete understanding to students and limit conceptual errors. Gustiani, Widodo, and Suwarma (2017), similarly found that content and technical appropriateness are important for the students to comprehend technical terms and explain the concepts easily.

One of the experts' comments suggests changing the sentences/statements in the sustainability actions in part D to an affirmative or a more positive approach. According to Nucaro (2017), using positive words and encouraging students to meet expectations (the suggested sustainability actions) allows students to fulfil those expectations, or even surpass them. Therefore, it is important to modify the suggested sustainability actions from negative sentences to a more positive statement.

Varying comments were drawn from the journal of the students, positive and negative. Negative comments were used to modify and improve the developed learning materials to make it more relevant, appropriate, and understandable to students. Modifying and improving the developed learning materials would help to attain the objectives of the learning material, that is to enable the students to embody sustainable thinking (Kapur, 2019). Findings showed that there is a need to discuss the concepts in the developed learning materials briefly and in a way that is adapted to their level of understanding and grade level. Convergent to the study of Bar-Yam et al. (2002), the goal of education is to transmit knowledge with the goal that emphasises the development of the individual student, especially adapting the lessons or materials to students' ability levels. Students also suggested presenting more examples and more explanations in the developed learning materials. As reported by Rawson, Thomas, and Jacoby (2015), abstract concepts can be instantiated in real-world situations by presenting students with concrete examples, a common pedagogical approach for supporting learning of declarative concepts.

## Conclusion

Learning materials were developed utilising sustainability pedagogy, with introduced features such as issue-based, sustainability-themed, contextualised, and reflective. The five developed learning materials are valid and passed the criteria of DepEd (Department Education) according to

LRMDS (The Learning Resources Management and Development System). Students found the developed learning materials interesting, comprehensible, promote awareness, relevant to community's environmental issues, and helped students to express their opinions. Additionally, the developed learning materials need to be modified per area, introduction, objective, definition of terms, sustainability-themed, activity, and reflection. The study recommended that the valid and modified DLMs utilising sustainability pedagogy may be used by Biology Teachers in their lessons and can still be improved and further contextualised. Sustainability pedagogy may be employed in other topics in ecology and environmental science to explore its validity and effectiveness.

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Research Paper

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# Assessment of Teachers' Knowledge and Practices on Laboratory Waste Disposal

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## Abstract

*In alignment with the United Nations Sustainable Development Goals 2030 (UN SDGs 2030), which emphasise the importance of ensuring education inclusivity and quality for all, this study investigated the quality of education in the context of science teachers' knowledge and practice related to laboratory waste disposal. Understanding the critical role that science teachers have in fostering a safe and sustainable learning environment, the research focused on the gap between the awareness and application of proper laboratory waste management techniques. Filling this gap is imperative not only for the well-being of the school community but also for the contribution to the broader goals of sustainable development outlined in the UN SDGs 2030. Consequently, this study assessed teachers' knowledge and practice in handling laboratory waste disposal. As a qualitative research, this study used a phenomenological design with semi-structured interviews using open-ended questions to gather data from 20 public science teachers from Santa Rosa City and Cabuyao City in Laguna Province as respondents. Regarding teachers' knowledge, three themes emerged, namely: (1) recycling techniques, (2) waste segregation and disposal, as well as (3) treatment of laboratory waste. However, the majority of science teachers admit that they have limited knowledge of how laboratory waste should be disposed of. They tended to apply basic knowledge of waste management that they already knew, despite being aware that laboratory waste should be treated differently from solid waste generated by our offices at schools. Teacher's practice on laboratory waste disposal involved three steps, including identification, segregation of laboratory waste, and laboratory waste management disposal. Unfortunately, all were found to be inadequate to maintain proper laboratory waste disposal at schools. Hence, this study highlights the need to enhance awareness and facilitate training on laboratory waste disposal among teachers in public schools. Specific training and education on laboratory waste management, treatment, and disposal are essential for teachers in public schools who work in laboratory settings. Regular monitoring and evaluations of teachers' laboratory waste disposal practices should also be implemented to ensure that they adhere to the proper procedures.*

**Keywords:** Science Laboratory; Waste Disposal; Teacher's Knowledge and Practices

## Introduction

In all schools, it is necessary to evaluate teachers' actions and knowledge regarding the disposal of laboratory waste. To foster a safety culture among teachers and students in the science laboratory, it is essential to set appropriate ethical norms and rules. Laboratory malpractice may be committed when a member of the laboratory staff, a technician, or even a teacher fails to oversee the safety, accuracy, and precision of laboratory work (Ponferrada et. al., 2017). The byproducts (waste) of scientific experiments conducted at schools can be exceedingly toxic or hazardous to students' health and the environment; therefore, it is essential to learn how to dispose of such waste in accordance with safety laws. Liquid, gaseous, and solid waste products are unavoidable by-products of laboratory investigations. If these wastes are not managed appropriately, they can contribute to environmental harm, pose health risks, and irritate students.

Waste generation and disposal have become increasingly problematic worldwide in recent decades (Starovoytova, 2018). According to him, how waste is managed, stored, collected, and disposed of will determine if the environment is clean, pleasant, healthy, and sustainable. Waste cannot be prevented in any way.

A secure classroom atmosphere can drastically improve both students' performance and learning quality. However, indiscriminate waste disposal by students and teachers who do not employ effective waste management practices pose a serious problem that could impede the educational philosophy of any country in the future.

A sustainable environment is necessary for the growth of the next generation of scientists who will drive our economy forward despite the collapse of the global economy. The adoption of poor waste management practices, mainly the procedures, in schools impedes sustainable growth on all fronts and contributes to deteriorate environmental and public health conditions, including air and water pollution.

Unfortunately, both earlier and even contemporary biological and physical science education curricula do not place sufficient focus on the acquisition of practical skills for the construction and operation of secondary school laboratories. That is the problem, even though science teachers are obliged to know how to maintain scientific laboratories operating efficiently.

Waste disposal management primarily consists of collection, transportation, and disposal. A comprehensive waste management strategy for a school could involve activities such as collecting, sorting/separating biodegradable from non-biodegradable materials, modifying, treating, and recycling waste (Licy, Vivek, Saritha, Anies, & Josphina, 2013).

The knowledge and practices of science teachers, who are the foundation of high-quality science instruction at the elementary and secondary levels, must be evaluated immediately. According to Abne et al. (2017), literature is essential for improving solid waste management. This will advance the methods for the disposal of solid waste, as well as the adoption of recycling solutions and information.

Future science instructors must have a thorough understanding of solid waste management to significantly contribute to environmental sustainability. Consequently, the goal of this study was to assess the attitudes and knowledge of teachers regarding the disposal of laboratory waste, particularly at two scientific high schools in Laguna.

The management style used by teachers in the lab has been declining. Khan and Raza (2018) examined numerous issues with managing school science laboratory as well as potential solutions in their article. The authors pointed out several significant problems, such as limited funding, inadequate training for laboratory staff, and a lack of suitable facilities and equipment.

Additionally, according to Khan and Raza (2018), maintaining school science laboratory requires efficient waste disposal. They emphasised that waste in research laboratory might take the form of chemicals, malfunctioning machinery, or even biological materials. These materials can create environmental problems, health hazards, and even legal obligations if they are not disposed of properly.

Another problem that impacts waste disposal in research laboratory is inadequate training for laboratory staff. Khan and Raza (2018) discovered that a large portion of laboratory staff lack knowledge of how to properly dispose of laboratory waste. Due to this lack of information, items may be disposed of improperly, posing risks to both the environment and human health.

Smith (2019) also emphasised the fact that many high schools do not have adequate waste management procedures, which could pose risks to both students and the environment. According to Patel and Patel (2017), many institutions also had poor laboratory waste management procedures, while Chen and Wang (2016) discovered that in China, many laboratories lacked the necessary equipment, and the staff members were not properly educated in waste management procedures.

This prompted the study to assess teachers' knowledge and practices of laboratory waste disposal because of what appears to be a lack of knowledge and practice for laboratory upkeep.

**Research Questions**

The managerial culture among teachers in the lab has been deteriorating. Their attitude in using laboratories and their familiarity with proper disposal procedures for laboratory waste can be used to assess the managerial culture. The health risks caused by the waste towards people's lives and the environment are frequently ignored in unoccupied scientific laboratories or in mismanaged reaction solutions. This study assessed teachers' knowledge and practices of laboratory waste disposal because of a lack of managerial culture in upkeeping laboratory.

This study aimed to assess teachers' knowledge and practices in handling laboratory waste disposal. Specifically, it seeks to answer the following questions:

1. What is teachers' knowledge of managing laboratory waste disposal?
2. How do teachers practice handling laboratory waste disposal?
3. How do teachers handle proper laboratory waste disposal?

**Methodology**

As qualitative research, this study used phenomenological design to gather data. The knowledge and practices of secondary school classroom teachers regarding laboratory procedures are investigated. A phenomenological design is practical for identifying knowledge and practices of science teachers on laboratory waste disposal because it enabled the researcher to gain an in-depth understanding of the phenomenon, understand the teachers' perspective, remain flexible in data collection and analysis, as well as identify themes and patterns, gaps, and areas for improvement (Moustakas, 1994).

In this study, the interview method was employed within the framework of phenomenological patterns to elicit instructors' thoughts on the procedures utilized in science laboratories, especially concerning waste disposal. An extensive structured interview with open-ended questions served as the researcher's main strategy for collecting data. The interview approach allowed researcher to pose questions that are flexible, interactive, and encourage further conversation to reveal the experiences and meanings of the phenomenon. The population of this study consisted of 20 science teachers from Santa Rosa Science and Technology High School in Santa Rosa City and Pulo National High School in Cabuyao City, both from Laguna Province.

The instrument for data collection was an interview guide designed by researcher that underwent expert validation. The experts involved in instrument validation test were selected Science and English teachers. Consent forms were also provided before the conduct of the interview. Participants were informed about the study and were assured that they could withdraw at any point, even in the middle of the study, if any ethical issues arose.

**Data Analysis**

Analyses of qualitative data were used to assess the research data. In this type of analysis, the data in a form of text was divided into smaller pieces (expressions, sentences, or paragraphs) and labelled. After that, the labels were grouped into themes with a code name (Saldaña, 2016; Braun & Clarke, 2006; Miles & Huberman, 1994). The code name may be developed from participant comments, the researcher's explanations, or ideas found in the social sciences past research. Additionally, the quotations provided direct support for the conclusions reached during the investigation into the transferability of the work.

Each participant's responses were explicated into paragraphs and each paragraph was coded. The categories were used to organise the codes. Sub-themes were created by combining the collected categories into one coherent paragraph. As a result, the categories and sub-themes that would be included under the main topic were developed as shown on a table. Then, each category and sub-theme were thoroughly discussed as the result of the study. Those results were backed by verbatim quotations from the participants' utterances to ensure the study's transferability. The participants' verbatim quotations were presented using code names.

## Results and Discussion

### Teachers' Knowledge on Managing Laboratory Waste Disposal

In this study, teachers' knowledge was classified into two categories: initial knowledge (pre-service teaching and 1-3 years of in-service teaching) and current knowledge (4 years to the present of in-service teaching). Upon analysis of the responses, Table 1 shows the common themes that have emerged.

**Table 1**. Teachers' Knowledge of Laboratory Waste Disposal.

| Teacher's Knowledge | Themes |
|---|---|
| **Initial Knowledge** | Recycling |
| | Waste Segregation and Disposal |
| **Present Knowledge** | Treatment of Laboratory Waste |
| | Laboratory Waste Management Protocol |

As shown, initial knowledge revolved around general knowledge of waste management and segregation. Those were evident from statements made by teachers during the interview when asked to share their knowledge or understanding of laboratory waste disposal before their in-service practice. Most responses were generic and have no direct relation to laboratory waste management. Responses such as: "*I would segregate materials accordingly (biodegradable, non-biodegradable, plastics, etc.)*" and *"I apply the 3Rs like reduce, re-use and recycle"* were common to all respondents. Those results were not surprising since no education course or subject specifically was given to the pre-service teachers regarding the proper methods to handle laboratory waste and its standard method of disposal. Although a majority of specialisation courses included laboratory, no course was offered to deliberately discuss about laboratory waste management and disposal in a proper manner. Therefore, those results were not surprising. Even though the majority of specialised courses contained lab work, there was not a single course that specifically addressed how to manage and dispose of laboratory waste. Those may be inferred from recent legislation (CMO 75, s. 2017) and earlier legislation (CMO 30, s. 2004), which set forth the policies, standards, and requirements for bachelor's degrees in secondary education for all Teacher Education Institutes (TEIs) across the nation.

Interestingly, present knowledge of laboratory waste has evolved alongside knowledge of waste disposal. Most teachers admitted that they would refer to the Material Safety Data Sheet (MSDS) to know how to properly dispose of laboratory waste. The majority of science teachers admitted that they had limited knowledge of how laboratory waste should be disposed of. They tended to apply basic knowledge of waste management that they already possessed despite knowing that laboratory waste should be treated differently from solid waste generated by our offices at schools. That suggested that while the teachers had a basic understanding of waste treatment, they may need more information on the specific regulations and guidelines in their laboratory.

**Teacher's Practices on Laboratory Waste Disposal**

As shown in Table 2, teachers' practice on laboratory waste disposal was categorised into three areas. The first concerned the identification of laboratory waste. Science teachers tended to identify the materials they use, assessing whether the materials were hazardous or not. In cases where they were unsure of its classification, they referred to the Material Safety Data Sheet (MSDS). Unfortunately, for biological experiments, some teachers admitted that they were not familiar with biosafety levels, thus they were not aware of how to properly treat biological agents. Moreover, science teachers also admitted that they do not know how laboratory waste is supposed to be treated and disposed of, especially chemical waste, even though some of them were chemistry teachers. Although they are aware of the protocol that should be followed, they rarely know how to put them into practice.

**Table 2.** Teachers' Practices in Handling Laboratory Waste Disposal

| Code | Responses |
|---|---|
| **Identification of Laboratory Wastes** | *I identify waste materials.*<br>*I check the materials to see if they can safely be disposed of in the sink or in the trash can.*<br>*I check the Material Safety Data Sheet (MSDS).*<br>*I evaluate waste according to its degree of hazard.* |
| **Segregation of Laboratory Waste** | *I check whether the chemical is toxic or not.*<br>*I used to separate the biodegradable materials from the non-biodegradable one.*<br>*I tend to separate the broken glass from any chemical spillage.* |
| **Management of Disposal** | *I practice the 3Rs; reduce, reuse, and recycle.*<br>*I would coordinate with my head teacher on how to dispose of hazardous materials or chemicals.*<br>*I use small amounts and very low concentrations of chemical reagents.*<br>*We just connect with the chemical disposal company and categorise our wastes using their guidelines.*<br>*We just refer to the MSDS on how to handle the chemicals.* |

This result is supported by the study of Kostov, P. & Kostova, P. (2020), which focused on laboratory safety and risk management in science education. They found that teachers lack knowledge and training in proper laboratory safety procedures and risk management. The study might also have highlighted the importance of providing teachers with training and resources to ensure the safety of their students in the laboratory.

The second area is the segregation of laboratory waste. Science teachers claimed that they usually check if the material is toxic or not, hazardous or non-hazardous, biodegradable or non-biodegradable, and chemical or solid waste. This practice helped them ensure that their students are safe from any potential harm and helps them decide how they will dispose of laboratory materials. They also mentioned separating broken glass from chemical spills, which is a good practice for safety reasons. However, they also mentioned that when it comes to chemical waste, they did not know how to treat and dispose of it properly, indicating a need for more training in this area. This data is in line with the procedure set by Department of Education (DepEd) as stipulated in the DepEd Order (DO) No. 48, s. 2006, which emphasises the importance of safety in science laboratories and requires the proper safety measures, such as segregation, to be implemented to ensure the safety of students and teachers.

Teachers' practices on laboratory waste disposal vary depending on their specialisation or the subject being taught in the class. Science teachers with specialisations in Physics and Biology claimed that they were not aware of a chemical waste treatment since they did not use chemicals during laboratory classes. However, in cases where chemicals were needed, they separated toxic from non-toxic or limited the use of such chemicals to a minimum (low concentration) so that they can simply flush it down the sink. For biological waste, some teachers claimed that they would simply dispose of it with a label along with other waste/garbage or bury it in the soil.

Lee, Kim, & Kim, (2021) found that there are certain laboratory skills that are common among all science majors, such as basic laboratory techniques, safety procedures, and data analysis. However, there may also be field-specific laboratory skills that are unique to certain majors, such as techniques for handling radioactive materials for physics majors or techniques for handling live organisms for biology majors (Tan & Tan, 2019; O'Neil, 2019).

Last area is laboratory waste management disposal. Science teachers with administrative functions are tasked to coordinate with these authorities. On the other hand, it was found that science teachers did not know this practice of coordinating with the proper authorities in handling laboratory waste disposals. No existing guidelines were found in schools that teachers could follow. One teacher mentioned that, "*Since there are no existing guidelines that they can follow, they would rely on private chemical disposal companies and would follow the guidelines set by these companies*". In cases where laboratory waste is piling up, they would coordinate with the local government unit, especially the City or Municipal Environment and Natural Resources Office (CENRO), to help the school dispose of it. They also mentioned using small amounts of chemical reagents and referring to the Material Safety Data Sheet (MSDS) for guidelines on handling chemicals. The teachers also stated that they connect with chemical disposal companies for the proper disposal of chemical waste but also mentioned that there are no existing guidelines that they can follow, indicating a need for more guidelines for laboratory waste disposal in their school. This was supported by researchers (Ancheta, 2017; Ioan, Onose, & Raluca, 2012; Perez, 2014; Paghasian, 2017; Sandham, 2014) which emphasized that waste management practice activities were minimal at the school environment.

The lack of knowledge and practices on laboratory waste disposal among teachers can have significant implications for environmental sustainability. Improper disposal of laboratory waste can lead to the release of hazardous materials into the environment, potentially causing harm to human health and the ecosystem. In addition, it can also contribute to pollution and the depletion of natural resources.

Furthermore, teachers play a critical role in promoting sustainable practices among students. If teachers lack knowledge and understanding of proper laboratory waste disposal procedures, they will not be able to effectively educate and guide students on how to reduce their environmental impact.

The lack of proper training and resources for teachers on laboratory waste disposal may also lead to non-compliance with regulations and laws governing waste management. This can result in penalties and fines for the school, which can divert resources that could be used for other sustainable initiatives.

In short, the lack of knowledge and practices on laboratory waste disposal among teachers can harm the environment and human health and can impede the implementation of sustainable practices in educational institutions. Schools must provide teachers with the necessary training and resources to ensure that they can effectively manage and dispose of laboratory waste in a way that is compliant with regulations and promotes environmental sustainability.

Upon visiting the school laboratories, the researcher found that no one was assigned to the management of these laboratories; instead, laboratory maintenance was assigned to the school's janitor who did not know laboratory protocols. They are merely tasked with cleaning each laboratory room. Science teachers were also assigned to each laboratory for monitoring laboratory use only

In summary, the study revealed that there is a gap in teachers' knowledge and practices on laboratory waste disposal, with many teachers lacking a thorough understanding of the proper procedures. This is a concern as it can lead to the improper disposal of hazardous materials, which can be harmful to the environment and human health.

## Conclusion

The results have shown that teachers' knowledge and practices on laboratory waste disposal are lacking. While general knowledge of waste disposal is important, it is not sufficient when it comes to managing, treating, and disposing of laboratory waste. Laboratory waste is unique and poses different risks and hazards compared to other types of waste. This requires specialised knowledge and practices to ensure the safe management, treatment, and disposal of laboratory waste. Therefore, it is essential for teachers in public schools who work in laboratory settings to have specific training and education on laboratory waste management, treatment, and disposal. Without this specialised knowledge, they may not be able to effectively manage and dispose of laboratory waste, putting students, staff, and the environment at risk. Public schools need to provide teachers with the necessary training and resources to ensure that they have the knowledge and skills to safely manage, treat, and dispose of laboratory waste to protect the health and safety of students, staff, and the community.

In addition, the identification, segregation, and management of laboratory waste are crucial themes in ensuring the safe and compliant disposal of laboratory waste in public schools. The ability to properly identify laboratory waste is the first step in ensuring its safe and compliant disposal. Without proper identification, teachers may not be able to determine the appropriate method of disposal, which could lead to accidental exposure to hazardous materials or non-compliance with regulations.

Segregation of laboratory waste is also important to ensure that it is properly treated and disposed of in a way that protects the health and safety of students, staff, and the environment. Different types of laboratory waste may require different methods of disposal, and segregation ensures that the waste is handled and disposed of appropriately.

Proper management of disposal is also essential in ensuring the safety of students, staff, and the community. This includes knowledge of the regulations and laws governing laboratory waste disposal, as well as the appropriate methods for handling and disposing of various types of waste materials. Teachers should be trained to manage the disposal of laboratory waste in a way that is compliant with all relevant regulations and minimises the risk of accidents or exposure to harmful substances.

Public schools must provide teachers with the necessary training and resources in these three themes of identification, segregation, and management of laboratory waste disposal. This will help to ensure that students and staff are protected and that the school is in compliance with all relevant regulations. Regular assessments and evaluations of teachers' laboratory waste disposal practices should also be implemented to ensure that they are adhering to the proper procedures.

In conclusion, this study highlights the need for increased awareness and training on laboratory waste disposal among teachers in public schools. Improper disposal of laboratory waste can have serious consequences for the environment and human health, and teachers play a vital role in promoting sustainable practices among students. Therefore, it is essential that teachers have a thorough understanding of the proper procedures for handling and disposing of laboratory waste, and that they receive regular training and resources to ensure that they can promote sustainable practices in the laboratory and school environments.

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Research Paper Open Accsess

# STEM Students' Motivation, Interest, and Career Direstion Amid New Normal Education: A Narrative Inquiry Research

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## Abstract

*The abrupt transition of learning modalities and the global health crisis brought by the COVID-19 pandemic have reshaped the learners' experiences and insights, particularly in STEM (Science, Technology, Engineering, and Mathematics) education. Hence, this study was conducted to explore the stories of senior high school STEM learners on how the new normal education impacted their motivation, interest, and career direction using a narrative inquiry research design. Purposive sampling was used to select twelve participants from a public senior high school offering the STEM strand. A Semi-structured interview guide, which underwent expert judgment, was used to collect data. After securing consent forms, in-depth interviews were conducted via online platforms. Data collected were transcribed, coded, categorised, and thematised, applying Polkinghorne's analysis of narratives. Results illustrated that students' (a) motivation has declined, causing discouragement in STEM activities, however, their passion and goals kept them eager; (b) interest was elevated by their constant commitment to STEM endeavours, yet less enthusiasm has become evident; (c) career direction was still definite as fuelled by relevance, though some have restructured theirs due to the drastic change of circumstances. Furthermore, students devised adaptive strategies to further enrich themselves in STEM undertakings such as improving STEM identity, fostering STEM competence and habits, reorganisation of tasks, and peer collaboration. The findings of this study led to the creation of an action plan to further improve the STEM learning experiences of students amid the radical educational change. This research employed a holistic perspective as it considers the nature, aspect, and meaning of students' narratives.*

**Keywords:** Narrative inquiry; Motivation; Interest; Career direction; STEM strand; Senior high school; New normal education; Philippines

## Introduction

The COVID-19 outbreak has drastically changed the learning delivery of educational institutions in the Philippines, affecting almost 28 million students due to the closing of schools and the abrupt transition and implementation of new learning modalities (Tria, 2020). The conventional in-person classes have immediately shifted to distance learning in order to ensure the safety of students, teachers and education staff, as well as to prevent the further spread of the virus. However, the impacts of the pandemic have been severely felt by students, creating significant learning gaps which led to a decline in their academic achievement, particularly in literacy and numeracy skills (George et al., 2021; Pokhrel & Chhetri, 2021). In the same vein, it was reported that depression, stress, and anxiety created obstacles to students' learning, hence raising the need to address mental health issues exacerbated by the pandemic (Silva et al., 2021). Furthermore, students from low-socioeconomic (SES) households had limited or no access to relevant technology tools required for distance learning (Pokhrel & Chhetri, 2021). With that, a large percentage of senior high school students who reported that they had planned to attend a four-year college dropped to below 50%, as their plans of going to college have been derailed by family, financial, and health complications (Point, 2022). While the reopening of schools has commenced, many challenges are still felt. Thus, a time for educational reinvention is desperately needed.

The STEM strand focuses on the significant connections that exist in the disciplinary concepts of science, technology, engineering, and mathematics (Bolds, 2017), enabling learners to foster a culture of efficiency, productivity, and innovation. This further promotes the increased use of scientific and technological breakthroughs to improve various sectors, including production, health, education, energy, and infrastructure systems, and others (NEDA, 2017). After finishing the track, the graduates are expected to pursue careers aligned with the objectives of STEM to become scientists, doctors, researchers, engineers, agriculturists, automation and robotics professionals, software developers, information system analysts, etc. To realise these targeted goals, learners are immersed in an extensive STEM-focused curriculum employing instructional designs centred on project, problem, and design-based pedagogies. Developing STEM competencies has been regarded as an essential goal to nurture literacies that will help to solve the pressing problems brought about by the dynamic changes in twenty-first-century knowledge-based economies.

The senior high school STEM curriculum is designed to develop learners' knowledge and skills utilising more innovative approaches that emphasise the attainment of critical thinking, creativity, communication, problem-solving, self-direction, and scientific literacy (Sarac, 2018). This is intended to generate competent professionals equipped with 21st-century skills, who can contribute to the advancement of the country's economic, social, and environmental aspects. STEM education is seen as a powerful driver that can address the complexities brought about by global challenges (Kelley & Knowles, 2016). In turn, the demand for STEM graduates has significantly increased, as these individuals are believed to acquire compounded talents across STEM disciplines, enabling them to understand and deal with real-world crises (Yata et al., 2020). STEM education has also been affected by the crucial effects posed by the COVID-19 pandemic. It has hampered the recruitment, continuous growth, and motivation of students as the future STEM professionals (Forakis et al., 2020). In response, senior high schools offering a STEM strand have devised intervention plans to continue the education among students, allowing them to maximise STEM learning. However, the lack of physical interaction and laboratory exposure elicited difficulties at their end. This is true for subjects that require intensive laboratory work using science equipment and tools (Byrnes et. al., 2020). Moreover, critical topics in sciences that enhance engineering studies have posed considerable issues due to the abrupt switch of modalities, as engineering is dependable on the practical application of information, which is highly relied on in-person classes and laboratory work (Baltà-Salvador et al., 2021). Such situations impacted students' behaviour which led to a lack of motivation, interest, and enthusiasm in their strand (Marzoli et al., 2021).

Students' career direction is reflected in their chosen strand in senior high school. During these training and formative years, they develop their motivations to guide them along their chosen path. Motivation, as a prime construct of learning, is a significant aspect towards achieving a goal (Hariri et al., 2020). In a study conducted among STEM students at a public academic institution in Lipa City, Batangas it was found that their primary motivation is their achievement, in which they gain satisfaction when they successfully achieve something in science learning (Albalate et al., 2017). Meanwhile, a study at a public secondary school in Zambales, Philippines, revealed that the motivation for STEM students to pursue their strand is influenced by their future career goals (Rafanan et al., 2020). Furthermore, a study carried out in a technical school in Iligan City, showed significant findings that senior high school learners engaged in remote learning are still motivated to learn science because they are aware of its use and importance in their daily life affairs (Aque et al., 2021).

Another factor that shapes students' outlook in STEM education is interest. Interest, as a construct in research studies, is mostly understood as a phenomenon that emerges from an individual's interaction with their environment (Silvia, 2016). The implementation of different modalities has affected students' interest towards their current situation. In a study conducted at a private school in Dasmarinas, it was shown that Grade 12 students preferred the online distance learning modality in science subjects due to its convenience and flexibility, hence, raising students' interest in interaction, collaboration, and creativity (Pinar, 2021). Also, a parallel study conducted in four secondary schools found that remote learning enhanced students' self-efficacy and developed an interest in STEM career (Thisgaard & Makransky, 2017). In contrast to these advantages, another study conducted among students indicated that in-person classes are still the most preferred modality for learning, since remote learning led to unclear instructions and directions, difficulty in group dynamics, trouble in retaining information (Tareen & Haand, 2020), and lower academic achievement (Francis et al., 2019). Additionally, a study conducted in public institutions from a foreign country revealed that the attitude and interest of students towards STEM learning in distance learning were negative and low, respectively (Vance et al., 2015).

Several studies have explored the effects of COVID-19 pandemic on STEM education, particularly among STEM students. A recent study in Zambia revealed a significant decrease in the performance of Grade 12 students in STEM subjects considering the context of the pandemic, resulting in the immense drop in national achievement (Sintema, 2020). Another study, which was conducted in the United States, stated that most STEM students were observed to have less emotional engagement and participation in science amidst remote learning. This contributed to their perception of science value (Wester et al., 2021). Although they were not greatly worried about the impacts of the pandemic on their chosen career paths, most of them had negative reactions to the abrupt shift in learning modalities, as this affected their acquisition of STEM skills (Desrochers et al., 2020).

Despite these significant findings mentioned, the majority of the studies conducted on STEM education were based on foreign context, hence, lacking significance in terms of localisation in the Philippines. With that, they may not be applicable and relevant in the local context. Also, some of which were conducted prior to or during the COVID-19 pandemic, hence, data may not be pertinent to the current situation.

Therefore, this study was conducted to gain an in-depth understanding of senior high school STEM students' motivation, interest, and career direction amid the new normal education, through their shared stories of narratives. This may serve as a foundation for creating action plans to further enrich the STEM learning experience of students. Furthermore, this may also serve as a basis for future studies to further explore STEM students' perspectives, beliefs, and perception on STEM education during the new normal education.

**Research Objectives**

This narrative inquiry research study was conducted to explore the senior high school STEM students’ motivation, interest, and career direction amid the new normal education. Specifically, this study sought answers to the following:

1. Determine how the new normal education affected senior high school STEM students in terms of:
   1.1 motivation,
   1.2 interest, and
   1.3 career direction.

2. Ascertain the adaptive strategies devised and employed by senior high school STEM students to enrich themselves in STEM undertakings amid new normal education.

3. Construct a plan of action that may help to elevate the motivation, interest, and career direction of senior high school STEM students amid new normal education.

## Methodology

### Research Design

Narrative research was used as the research design of the study. Narrative research or inquiry-based study is a relatively contemporary qualitative methodology that focuses on life stories as the essence of people-oriented sciences (Ntinda, 2019). This design was employed as an applicable research design since the present study attempted to explore the senior high school STEM students' experiences. It focused on their individual stories and personal narratives regarding how their motivation, interest and career direction were impacted during distance learning amid new normal education. Using the students’ experiences as a research approach promotes critical reflection, as well as a sense of voice and self, which could be multilayered and understood deeply (Hickson, 2015).

### Participants and Sampling

The participants in this study consisted of twelve students from a public senior high school offering the Science, Technology, Engineering, and Mathematics (STEM) strand in one city schools division in the Philippines. Purposive sampling was used to select the participants of the study. This is a non-probability sampling technique in which the researcher relies on their sound judgment when choosing members of the population to participate in the data collection. This method was used as it provided cost-effectiveness and time-effectiveness sampling procedures for selecting samples, which are essential at the present times in which the resources are currently limited and social interactions are hindered (Etikan, 2016).

### Research Instrument

A researcher-made semi-structured interview guide was used as the main data collection instrument of the study, aiming to obtain the senior high school STEM students’ stories on how the new normal in education affected their motivation, interest, and career direction. The tool, consisting of 22 questions, was ensured to be aligned to the objectives of the study.

To ensure the validity and alignment of contents, the research instrument underwent to expert validation. Three experts from the fields of education sciences, English language, and research and statistics were invited to serve as validators of the research instrument. After the aforementioned validation process, the research instrument was tested to a small sample (n=3) consisting of individuals who were not the main participants of the study. This step aimed to obtain feedback for possible revisions and adjustments. After which, the research instrument was administered to a larger sample group (n=12).

### Data Collection

Permission to conduct the study was secured before the actual data collection. Once approval was granted, informed consent documents stating the purpose and nature of the study, procedure, participation, risks, and confidentiality was secured from the identified participants. Provided that they agreed to participate, they were asked to fill out their direct consent.

In-depth interviews were conducted among selected senior high school STEM students to explore their motivation, interest, and career direction amid the new normal education. The interviews were scheduled according to the participants' availability. Phone calls, Messenger calls, Google meet or Zoom meeting were used as online interview platforms, depending on the participants' convenience and preference. The interview protocol followed the three serial in-depth interviews developed by Seidman (1998). This procedure addressed the personal narratives and experiences of students in distance learning. It involves an interview segment that explores the influence of the new normal in education on their motivation, interest, and career direction. This also encompasses an examination of their adaptive strategies to navigate STEM pursuits despite the challenges. The third interview integrates the information gathered from the preceding sessions to articulate the unique stories of each participant.

During the interview, predetermined questions were asked. The participants were allowed to answer in their own words. Since this was a semi-structured interview, the researcher had the flexibility to ask additional questions to ensure clarity and in-depth understanding. Each interview session lasted for about 45-60 minutes. The interviews were audio-recorded and kept with meticulous attention to ethical standard and confidentiality.

### Data Analysis

The research utilised Polkinghorne's Analysis of Narratives (1995) to analyse the data gathered from the audiotaped interviews. Polkinghorne's approach underscores the creation of concepts that establish a categorical identity based on specific details obtained from the collected data. The process commenced by scrutinising life narratives to identify shared concepts. Subsequently, coding frameworks were developed to organise the data into clusters of common themes. Additionally, these grouped data sets underwent further scrutiny to pinpoint characteristics that designated them within specific categories. Ultimately, the themes resulting from this analysis contribute to a cohesive narrative. Moreover, a member-checking procedure was implemented to validate the trustworthiness of the data.

## Results and Discussion

### The Effect of New Normal Education to Senior High School STEM Students

1. ***In terms of Motivation***

#### Abrupt change leads to discouragement

Though education is pursued through different learning modalities, the abrupt transition, from conventional in-person classes to distance learning, caused discouragement and pessimism in students to continue their successful undertakings in STEM affairs. Students' mental health and psychosocial well-being were greatly impacted by the COVID-19 pandemic, as they were stuck at their homes limiting the social interaction they needed for continuous learning, peer engagement, and participation in various activities. In the same vein, they struggled immensely as distance learning modalities were new to them, requiring significant adjustment and massive coping (Selco & Habbak, 2021). This dramatic situation elicited a passive mindset among senior high school STEM students. The newness of learning delivery, its rapid implementation, unfamiliarity with its nature, and the struggle for survival during the pandemic decreased their enthusiasm and zeal rooted in significant amounts of stress, uncertainty, and discomfort (Minichiello et al., 2022).

*"I still want to pursue my strand and achieve my goals, but what is happening around us makes me scared, doubtful, puzzled, and uncertain. It is like, I totally lost my drive and felt discouraged to continue the usual things I do." – Participant A*

*"Learning STEM is better if classes are still conducted in-person. However, we must follow certain protocols to ensure safety and protection, but distance learning makes me unmotivated. I do not necessarily appreciate STEM learning in this modality." – Participant H*

**Passion and goals keep the eagerness**

Despite being unmotivated towards STEM learning amid the new normal education, their inherent drive, rooted in their passion and goals, keeps them eager to move forward and pursue their education. Though faced with anxiety, uncomfortable situations at home, and inexperience with distance learning, their strong desire and commitment to their dreams allow them to maximise their abilities and enrich their engagement towards STEM learning. Still, many students have become committed and dependable on their education to embrace future opportunities (Cromley & Kunze, 2021).

*"Despite all the hassles and bustles brought about by the current situation, what really strengthens me is my strong will to reach for my dreams and achieve my goals" – Participant B*

*"I still think that I should continue my studies as long as I can because this can be a way to achieve my dreams and goals in life." – Participant D*

***2. In terms of Interest***

**Constant commitment to STEM endeavours heightens interest**

Senior high school STEM students still show heightened interest in STEM learning as it piques their curiosity, significance, and enthusiasm in science, mathematics, and other related disciplines. Most of the students have a strong inclination towards STEM, as evident by their active participation and vigorous engagement in STEM endeavours, hence promoting a positive outlook towards STEM education. Despite being uncertain, their constant commitment to STEM undertakings allows them to maximise their learning effectively. As interest towards STEM continuously grows, students develop enjoyment, motivation, and good learning habits. Furthermore, some students even mentioned that the interest comes from their aspirations to become STEM professionals who can contribute to nation-building. Hence, students still express high levels of satisfaction and interest in STEM learning (Paechter & Maier, 2010) despite the pandemic and distance learning modality.

*"Though the pandemic hit differently, and it is very challenging to study, my interest in science subjects, as well as technology and engineering things, did not change. This paves the way for me to still pursue STEM" – Participant J*

*"I still become more interested in STEM, particularly in becoming a professional under it. I really find its relevance fascinating, especially during these trying times that only STEM knowledge and skills can help us to overcome the virus." – Participant G*

**Less enthusiasm due to uncertainties**

Despite the continued STEM learning through distance learning modality, it is inevitable to experience less enthusiasm due to the turn of events, particularly in the trying times of the pandemic, in which everything seems uncertain. This has led to the diminishing fervour in STEM learning experiences as senior high school STEM students struggle to cope with the new normal education amid anxiety, isolation at home, mental health cases, and emotional breakdowns. Such circumstances were normal since everyone subjected to unusual situations needs time for recalibration and adjustments. Moreover, students find joy in face-to-face classes when compared to other learning modalities such as online distance learning (Wladis et al., 2015).

*"I still want to pursue STEM learning, but the enjoyment becomes lesser. Perhaps,*

*this is because of the saddening situation we face nowadays, where everything seems unsure." – Participant E*

***3. In terms of Career Direction***

**Certainty in STEM career path**

Senior high school STEM students remained steadfast in determining and assuring their career path despite the drastic change of circumstances brought about by the COVID-19 pandemic. They retained their innate drive to pursue their STEM career directions rooted in their personal aspirations and goal setting that they carried even before the pandemic (Rafanan et al., 2020). Their dreams and goals serve as the genuine purpose to hold to their STEM career paths, hence, strengthening decision-making, personal outlook, and determination.

*"If I try to imagine myself doing a different career or entering a different profession, it may be just felt wrong. Regarding my career direction, the new normal does not necessarily affect my decision towards my career path. As a matter of fact, I feel more eager to achieve my STEM goals." – Participant L*

*"Ever since, I want to be a doctor. I knew it even when I was a child. The pandemic may have changed some of our plans, but my career direction remains solid." – Participant D*

**Strengthened STEM career choice**

Senior high school STEM students' career direction is powered by a lot of influences – family, peers, interests, and media. Family, having a personal connection to the student's lives and well-being, shapes their STEM career direction. Peers also contribute as they serve as strong allies to give encouragement and advice. Personal interest gains greater value as it deepens on one's career direction, rooted in personal gains, satisfaction, and drive. Media, on the other hand, poses a significant influence on one's choices, decisions, and selections. The influences coming from these factors help the learners to mold and shape their career choices, and later on, recalibrate their directions.

*"My family helps me to build my career path. They give me advice, which can truly help me to fulfil my ambitions." – Participant F*

*"As I watch the series Grey's anatomy, I cannot help but to picture myself wearing a white gown and doing the same things that the doctors do in the series. I am truly much inspired with that." – Participant K*

*"Still, it all boils down to my personal interest. Despite the motivations and adviceI received, I still consider what I want because this can truly satisfy my being, aspirations, and goals." – Participant B*

**Redefining career paths**

The widespread impact of COVID-19 pandemic has changed the decisions of some senior high school STEM students to recalibrate and redefine their career directions. Some of them were inspired to take on a career due to the present context they are in, as well as the new adaptations they experienced. Other STEM students, though still adhered to STEM endeavours, discovered new interests and developed new skills, which changed their sense of mindsets regarding their career paths (Santos, 2020). Nonetheless, all professions are good to make the community and the larger society a better place to live.

*"I love to be in the STEM profession, that is why I took STEM strand. However, with the current scenario we have in our family in which our socio-economic status has declined, I tend to change my career direction and consider the path which is more practical for us." – Participant C*

*"Seeing the vulnerable healthcare system in our country during the pandemic, it pushed me to take on a career path leading to a*

*positive change of that and that is being a medical officer. I want to contribute in providing a better healthcare system for the Filipino people." – Participant H*

**Senior High School STEM Students' Adaptive Strategies to Enrich Themselves in STEM Undertaking amid New Normal Education**

**Developing STEM identity**

STEM identity is defined as the way individuals make the concept of fitting in within STEM fields, making meaning of science experiences and how the community structures possible meanings (Hughes et al., 2013). In such a case, the senior high school STEM students develop their STEM identities as they solidify their aspirations and goals towards STEM career path. They think of themselves as not just passive learners, but dynamic individuals who contribute to the success of science learning. Henceforth, the senior high school STEM students continuously engage themselves in activities and immerse themselves in various undertakings which deepens their interest and elevate their attitude towards STEM. Furthermore, STEM identity has been shown to have a powerful role in an individual's success in educational environments, as well as on their career goals.

*"Though implemented in distance learning modalities particularly online, I always join webinars about various topics in sciences. I also immerse myself in STEM research activities through science investigatory projects and inquiry-based undertakings." – Participant A*

**Fostering STEM competence and habits**

Senior high school STEM students participated and engaged in activities to continuously develop their knowledge, skills, talents, and habits which are deemed necessary in STEM learning. They enhanced different facets and aspects of themselves towards the attainment of STEM competence and habits to acquire inquiry, creativity, persistence, and science literacy. This can be totally achieved as students continuously grow in an extensive learning environment in which STEM is inculcated as a way of life. Moreover, such competence and skills are significant for STEM workplace in the future (McGunagle & Zizka, 2020).

*"I continuously engage myself in STEM through the learning endeavours I participated in. In this way, I can develop different skills and enhance my knowledge on STEM as an integrated discipline which is essential in solving problems in the country." – Participant C*

**Reorganisation of tasks**

It is no less than a fact that being a senior high school student in a STEM strand entails a lot of challenges as tasks continuously pile up. A different sense of hard work, responsibility and discipline is required. Senior high school STEM students reorganised their tasks through exhibiting self-directed learning practices, management procedures, and independent learning accountabilities. The new normal education allows the students to nurture their organisation practices to promote responsible learning in order to put time for everything in the logical sequence of priorities. In the case of STEM endeavours, the students were able to give emphasis and consider the importance of STEM learning especially when one finds its relevance in the nature and purpose of life affairs. Nonetheless, the organisation becomes the foundation of clear thoughts and a proper mindset.

*"I was able to develop good time management techniques so I can finish all my tasks depending on its schedule and level of importance. Since I am enrolled in the STEM strand, I get to reorganise my tasks so I can give priority on it as it requires a lot of understanding." – Participant G*

## Peer collaboration

Collaboration is one of the 21st century skills that learners shall achieve to thrive in the knowledge and skill-based society. Collaboration is a significant scheme to attain participation, engagement, inclusivity, and cooperation. In the case of senior high school STEM students, they participate and join club activities, interact with their peers regularly, engage in group dynamics, and perform socialisation to develop a good definition of collaboration. Despite the limitations of new normal education as intensified by the COVID-19 pandemic, the students still maximise the development of harmonious relationship with their peers. Research shows that building a sense of community among students improves student learning, retention, and student satisfaction, hence, improving their overall learning experiences (Fuller et al., 2015).

*"Working with my peers allows me to develop my collaborative skills. This also makes me practice my communication skills so I can express myself well. Additionally, it helps me learn more and develop other skills needed, as peers allows us to improve through their encouragements and constructive comments." – Participant D*

## Conclusions

Based on the results of the study, the researchers deduced the following conclusions:

1. The COVID-19 pandemic has made drastic impacts on the motivation, interest, and career direction of senior high school STEM students. The transition from conventional in-person classes to distance learning modality has caused discouragement to them. However, their passion and goals keep them eager to move forward and continue learning. Despite the uncertainties, their interest towards STEM endeavours was propelled by their constant commitment, yet less enthusiasm has become evident. Nonetheless, senior high school STEM students were still able to become definite of their career directions fuelled by interest and motivation. Yet, some students recalibrated and redefined their career goals due to the current circumstances.

2. Though some senior high school STEM students became unmotivated and lost interest in STEM learning amid new normal education, they were able to devise strategies on how to raise their motivation, interest, and career direction. Students improved their STEM identity through seeing themselves flourishing in STEM profession. They fostered STEM competency and habits through engaging and participating in various activities. They reorganised their tasks and exhibited proper time management to allocate time for their STEM endeavours. They maximised peer collaboration through constant interaction with others during activities and events.

3. A plan of action is proposed to develop the STEM learning experience of senior high school students amid new normal education. It hopes to bring positive and beneficial impacts towards their motivations, interests, and career directions.

| Programmes, Projects, and Activities | Objectives | Duration and Persons Involved | Success Indicators |
|---|---|---|---|
| **STEM Students' Counselling** | To assess the possible struggles and challenges of senior high school STEM students and provide necessary actions for their welfare. | Monthly<br><br>Senior high school STEM students<br>STEM coordinator<br>School administrator | 100% senior high school STEM students showed improvement in terms of their well-being, thereby increasing their |

| Programmes, Projects, and Activities | Objectives | Duration and Persons Involved | Success Indicators |
|---|---|---|---|
| | | Parents<br>Guidance counsellors | motivation towards STEM learning |
| **Career Guidance Orientations** | To orient, guide and direct senior high school STEM students and their parents on their career path and help them decide on their future directions based on their interests, talents, and skills. | Quarterly<br><br>Senior high school STEM students<br>STEM coordinator<br>School administrator<br>Parents<br>Teacher guidance designate<br>STEM advocates and professionals | 100% senior high school STEM students were oriented, guided, and directed on their STEM career path |
| **Establishing strong support system** | To encourage senior high school STEM students to become more engaged in STEM learning through support systems. | Weekly<br><br>Senior high school STEM students<br>STEM coordinator<br>School administrator<br>Parents<br>Peers<br>Other stakeholders | 100% senior high school STEM students were given support in whatever capacity they needed |
| **Allocation of resources to support STEM education amid new normal education** | To provide resources (financial, human, material) in students' learning in order to uplift STEM education amid new normal education | Yearly<br><br>Senior high school STEM students<br>STEM coordinator<br>School administrator<br>Parents<br>Stakeholders | 100% partners and linkages provide support through allocation of resources to enhance the STEM learning experiences of students |
| **STEM Month Culminating Activity** | To provide avenue of showcasing senior high school STEM students' talents, skills, and competence through various activities | Quarterly<br><br>Senior high school STEM students<br>STEM coordinator<br>School administrator<br>STEM clubs | 100% senior high school students participated in STEM month culminating activity, thereby raising their motivations and increasing their interests towards STEM endeavours |

## Recommendations

In view of the results of this study, these recommendations are hereby suggested.

1. Schools may provide opportunities to allow senior high school STEM students to explore and develop their motivation, interest, and career direction in STEM learning amid new normal education. They may be achieved through the provision of programmes, projects, and activities to help them cope and adapt to the new normal education.
2. Learners may continue growing and developing their knowledge, skills, talents, and habits aligned with the thrust of STEM education. This may help them become motivated, interested, and eager on their career pathways.
3. Family, peers, and teachers may provide a support system to cater to the mental and psychosocial needs of students either on matters concerning home and school. This

may help to sustain their motivations to learn and their interests steadfast.

4. Future researchers may conduct parallel studies investigating other factors of STEM learning concerning the effects of new normal education.

The proposed action plan may be considered for implementation to further develop the STEM learning experience of senior high school students amid new normal education.

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# Patterns of Metacognitive Levels in Chemistry Problem-posing

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## Abstract

*This study aims to describe the patterns of metacognitive levels in chemistry problem-posing activity of 76 undergraduate students from the Chemistry Education Department of Yogyakarta State University. Chemistry articles used in this investigation and the chemistry problems were classified based on the taxonomy of chemistry problem-posing skills where problems were later classified into seven metacognitive levels. Semiotic analysis was conducted to find the meaning of the signs found in the chemistry problems. This data analysis used and modified the three steps of the semiotic analysis with a phenomenological reduction method. Chemistry problem-posing in this current study shows the flow of the formulation for each problem. The input aspect for the formulation determines the process and the output result. The seven patterns are sorted into four participant types in submitting the chemistry problems: planning error (for poor, fair, and low intermediate level), evaluation error (for intermediate level), the imbalance metacognitive (for high intermediate and excellent level), and balance metacognitive (for outstanding level). The higher the level, the more complex and multiperspective determinations used for arranging a chemistry problem.*

**Keywords:** Developed fundamental skills; Practical work; Laboratory; Student's performance

## Introduction

Some studies about either question posing skills or problem-posing skills in chemistry that have been conducted, exposed the cognitive level in general and analysed the metacognitive level in a few (aramustafaoglu, et al., 2003; Blonder, et al., 2008; Demirdogen & Cakmakci, 2014; Gillete & Sangers, 2014). However, when students read the chemical reading as the precursor to problem-posing, they experienced both cognitive and metacognitive strategies (Khezrlou, 2012; Korpershoek, et al., 2015; Leopold & Leutner, 2015). This shortcoming is an effect of the difficulties to observe metacognitive aspects since all processes occur in the mind (Dunlosky & Metcalfe, 2009; Norris & Phillips, 2012; Grotzer & Mittlefehldt, 2012; Schraw, et al., 2012).

A think-aloud protocol could be the way to explore the metacognitive process (Ben-Eliyahu & Bernacki, 2015; Binbarasan-Tüysüzoglu & Greene, 2015). The advantage of this protocol is to give the outlook of both the memory work process and the actual thinking process when one is reading, understanding, strategizing, processing, and deciding (Wilhelm, 2001; Charters, 2003; Overton, et al., 2013). Particularly in chemistry reading comprehension, questioning the readers could be the indicator to estimate their understanding about chemistry in the reading context metacognitively (Herscovitz, et al., 2012; Kaberman & Dori, 2009a; Ghasempour, et al., 2013). Nevertheless, taxonomies used on some explorations depend on the variables of the parameters used (Herscovitz, et al., 2012; Kaberman & Dori, 2009b; Smith, et al., 2010; Pappa & Tsaparlis, 2013) to focus on a specific treatment (Bruck & Towns, 2009; Undersander, et al., 2017) and measure the cognitive to the metacognitive aspects

(Demirdogen & Cakmakci, 2014; Sanabria-Rios, D.; Bretz, 2010; Stickles, 2011), as it becomes a problem for teachers or assessors to determine their students' chemistry problem-posing skills metacognitively.

A semiotic analysis was selected to cover the problems above. This semiotic analysis could expose the meaning of the signs (Radford, 2000; Tang, et al., 2014), and how the signs express thinking processes especially in chemical thinking (Liu & Taber, 2016). The signs are meant as signifiers for the problems that students pose as a result of their metacognitive thinking process. Through this analysis, we can have a way to find the metacognitive processes on each problem posed qualitatively.

This current study is the advanced research of the chemistry problem-posing taxonomy by Sawuwu (2018) who classified chemistry problem-posing into seven metacognitive levels. Further explanations are needed regarding problem-posing patterns to help users classify metacognition levels based on the taxonomy. Following the phenomenological reduction technique by (Chopra, et al., 2017), this current study will analyse the textual data of chemistry problem-posing to find patterns used by participants in generating the problems. This study aims to describe the patterns of metacognitive levels in chemistry problem-posing activity based on the taxonomy.

## Methodology

### 2.1. Participant

The participants for this qualitative research are undergraduate students who have received the Chemical Equilibrium course at the Chemistry Education Department, Faculty of Mathematics and Natural Sciences, Yogyakarta State University, for the 2017/2018 academic year and are selected according to the following criteria: (a) the time span between having completed the topic of chemical equilibrium with the shortest test time to avoid random errors, and (b) students taking the test voluntarily to avoid the type of reader who was driven by obligation test (obligated reader). A total of 181 students from the Department of Chemistry Education (Chemical Sciences and Chemistry Education Study Program) FMIPA UNY for the academic year 2017/2018 (from Chemistry Education [CE] and Pure Chemistry [PC] programmes) matches the criteria (a), but only 110 students who could meet criteria (a) and (b). After being given the test, the remaining 99 participants whose data can be processed after being selected cannot determine the dominant reading technique they did. Then it was found that only 76 participants submitted one problem based on the test order and fulfilled all the other test conditions.

### 2.2. Instruments

The test instrument design was named the Metacognition Explorator in Chemical Equilibrium Problem-posing Skills. This instrument consists of a checklist of metacognitive activities during the test, articles on the skills of posing a chemical equilibrium problem, a problem-posing sheet, and a self-assessment sheet to determine the perceived performance of the participant's test. The characteristics and indicators of this instrument set are derived from previous qualitative studies (Sawuwu, 2018). Chemical articles used in the qualitative studies were compiled based on four components of chemical article structure (Herscovitz, et al., 2012), four types of chemical representations (Gilbert & Treagust, 2009a; Kaberman & Dori, 2009a, 2009b), four levels of humanistic approaches in the chemistry education tetrahedral (Sjostrom, et al., 2016), and three characteristics of scientific reading (Norris & Phillips, 2012). Through the think-aloud process, metacognitive reading patterns, and chemical problem-posing activities carried out by participants (in previous studies), six specific aspects were found to perfect the characteristics of the metacognitive stimulating chemistry article as shown in Table 1. Aspects of test instructions and article identity were used as the basis planning and readers' stimulation for the chemistry articles they will read. Aspects of the structure of the article and presentation of chemical representations are used to build the framework of chemical articles which become the main characteristics of chemistry reading and chemical understanding used in reviewing the chemical information provided. Aspects of the humanistic approach and the nature of chemistry articles are used to test the content of chemistry readings against the demands of 21st-century chemistry learning and the transfer of knowledge from chemistry readings to readers. The actual performance of participants' chemical equilibrium problem-posing skills was obtained from the assessment of the problems submitted based on the taxonomy of chemical problem-posing as shown in Table 2.

According to the four parameters above, the classification of the chemical problem-posing skill was determined by the attainment in each parameter. The level is converted to the score of each parameter. The sum of all scores is classified into seven categories as shown in Table 3.

**Table 1.** Characteristics of The Chemical Article.

| No. | **Characteristics** | Description |
|---|---|---|
| **1** | Title | Indonesia: *Kesetimbangan Karbonat dan Rusaknya Terumbu Karang*<br>English: Carbonate Equilibrium and Coral Reef Damage |
| **2** | Word and chemical representation | Word count 623 words; Two chemical equations = 15 words; A phenomenological picture = 39 words; An image (dependent multi-representation) =105 words |
| **3** | Text structure/paragraph | Socio-scientific issues of Minister Susi's policies and coral reef damage<br>Definition of coral reefs and their constituent components<br>Seawater provides carbonates<br>Seawater acidification process<br>Effect of acidification in chemical equilibrium perspective<br>Effects of trash and fish bombing |
| **4** | Keywords | Indonesia: *asidifikasi air laut, kalsifikasi terumbu karang, kesetimbangan karbonat*<br>English: seawater acidification, coral reef calcification, carbonate equilibrium |
| **5** | Independent representation | Coral reef damage (phenomenology); Acidification reaction (symbolic) |
| **6** | Dependent multi-representation | Coral reef calcification reaction (process-phenomenological-symbolic)<br>Carbonate equilibrium reaction (process-phenomenological-symbolic) |
| **7** | Socioscientific issues | Coral reef maintenance as a policy of the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia |
| **8** | Contextual | Sociochemistry: the importance of coral reefs for the future of the earth<br>Historichemistry: the impact of the industrial revolution on the future of coral reefs |
| **9** | Critical | Opens the reader's mind to pay attention to the preservation of coral reefs and the potential for overcoming them |
| **10** | Iteration | Requires repeat reading and decreasing reading rate on the seawater acidification process segment and its effect on carbonate equilibrium and coral reef calcification. |
| **11** | Interactive | Multi-representation = text and images for the acidification process of seawater<br>Persuasive = in the last sentence of the first and last paragraph |
| **12** | Principled | Contains one topic of thought, namely the balance of carbonates in the ocean and their effects on coral reefs. |
| **13** | Interdiscipline | Chemical equilibrium, biogeochemistry, maritime chemistry, biology |
| **14** | Intradiscipline | Chemical equilibrium, reaction rate, alkalinity, acid-based solution, salt hydrolysis |
| **15** | Reference | Primary sources: 9 journals<br>Secondary source: a national news site |

**Table 2.** Parameters in The Taxonomy of Chemistry Problem-posing Skill.

| Parameter | **Thinking level (TL)** | **Problem Structure (PS)** | **Chemical understanding (CU)** | **The Precision of The Chemical Concepts (CC)** |
|---|---|---|---|---|
| ***Signifier*** | the analysis of question word | The components of the problem posed | The use of chemical representation | the relationship of each information constructing the problem |
| **Score 1** | Failure | Posing nothing | Non-representation | Error (out-context) |
| **Score 2** | Definition | Posing a statement | Definition-unirepresentation | Misrequirement (failure in posing problem) |
| **Score 3** | Explanation | Posing a single question | Exploration-unirepresentation | Misconception (failure in preliminary knowledge) |
| **Score 4** | Exploration | Posing a coordinated question | Exploration-birepresentation | Misunderstanding (failure in understanding the chemistry aspect in the text) |
| **Score 5** | Expansion | Posing a simple problem | Correlation-birepresentation | Misrepresentation (failure in linking the chemistry concepts) |
| **Score 6** | Complex | Posing a complex problem | Multi-representation | Correct (Correct in linking the other concept to explain the chemical concept in the article) |

**Table 3.** Classification of The Chemical Problem-posing Skill.

| **The Sum of All Scores** | **Category** | **Signified** |
|---|---|---|
| 22 ≤ total ≤ 24 | Outstanding | The chemical problem is significantly in metacognitive level |
| 19 ≤ total ≤ 21 | Excellent | The chemical problem is lack of monitoring |
| 16 ≤ total ≤ 18 | Higher intermediate | The chemical problem is lack of the representations |
| 13 ≤ total ≤ 15 | Intermediate | A problem and a question are indiscriminate |
| 10 ≤ total ≤ 12 | Lower intermediate | The in-context chemical understanding is required |
| 7 ≤ total ≤ 9 | Fair | The understanding about the problem components is required |
| 4 ≤ total ≤ 6 | Poor | The task understanding is required |

## 2.3. Analysis

Problems posed by participants were analysed based on the taxonomy (Table 2). Then, the problems were classified into seven metacognitive levels based on Table 3. The semiotic analysis was conducted to find the meaning of the signs found in the chemical problems. This data analysis used and modified the three steps of semiotic analysis (for finding the signifier-signified relationship) with a phenomenological reduction method.

The first was an initial analysis that was the re-representation of the problems. The problems posed by the students were used as the particular signs in this analysis. Problems were identified according to its components: initial state (the data), final state (the goal), and operator (the limitation or possible ways to bridge the data problem to the goal). Chemical representations of the problems were also identified in the phenomenological, symbolic, model, or process representations. The second was the semiotic affordances. In this second phase, the first identification was on the question words they used in their final states as the signifier. The transcriptions about the problem-posing activities were used to reveal the meaning of the question words for each participant (to find why students used the question words). The meaning found was encoded to a semiotic expression. Every code was collected for each theme and was undertaken a second-cycle coding. The second identification was determined from the various expressions of each code in the first identification, so it was also for the next identification. The identification was terminated when the parameter found was estimated to complete the shortcomings of the previous parameter. The third was the iterative nature of the analysis. Comparing the analysis of patterns was conducted to have a consistent meaning for each signifier found. After each signifier had its own signified meaning, the themes were sorted ascendingly toward the complexity of the signified thinking towards the taxonomy.

A phenomenological reduction method was used to analyse the problems posed. All data was then reduced (horizontalization of data). After this reduction, the data was encoded and categorised in the same theme that represents the specific expressions and findings towards the metacognitive processes in the problems. The coding from the patterns were used to find neomatic themes (what the phenomenon is) and the coding from the semiotic analysis was used to find neosis themes (how the phenomenon is). Then, data verification was conducted to clarify and reinforce the themes. The neomatic themes were unified as a formulation of the textural definition and the neosis themes as the structural definition. By blending the textural and structural definitions and adding data interpretations, the themes were merged to be the essential definition of each pattern.

## 1. Results and Discussions

### 3.1. Pattern of The Chemistry Posing Activities of Each Metacognitive Level

The semiotic analysis of previous studies showed the classification of metacognitive levels based on the signifiers contained in the problems posed by participants. However, this present study can reveal the process of problem-posing chronologically. This process will help analyse and find the causes of low-level metacognition. If in previous studies the discussion of stages of chemistry problem-posing activities is separated from the chemistry problem-posing analysis, this current study will parallelise the pattern analysis in the five stages of chemistry problem-posing process and simplify them into an input-process-output diagram.

a. Poor level

The pattern of the problem-posing process for participants in the poor or very low category is shown in Figure 1. This pattern does not result in chemical problems. This is observed in the PC031 participant problem submission sheet as follows.

*"Fishing with dynamite can kill shellfish because dynamite can destroy the calcium carbonate skeleton."*

If the proposed statement is analysed (PS: 1), it is found that the statement is not in accordance with the test instructions (TL: 1), does not focus on the context of chemical equilibrium discussed in the article (CC: 2), and only examines phenomenological representations. (CU: 2).

| **Input:** → The chemical problem is the conclusion of a chemistry article. | **Process:** 1) Find the object of phenomenology of chemistry. 2) Find cases about the chemical object. → | | | **Output:** Rewrite the news sentence about the chemical object of the phenomenology. |
|---|---|---|---|---|
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

**Figure 1.** Pattern of the poor level in the chemistry problem-posing activity.

The poor level in the previous taxonomy (Sawuwu, 2018) signified that participants needed task understanding. From Figure 1, the pattern indicates that the statement posed is not a question but just a repetition of information.

b. Fair level

The pattern of the chemical problem submission process for the fair or low category is shown in Figure 2. Slightly superior to the very low level which does not pose a problem, this level is able to recognize the limits of the required chemical problems. This is observed from the PC042 participants' problem submission sheet as follows.

*"The increase in $CO_2$ in the atmosphere has an impact on coral reefs. The availability of $CaCO_3$ is influenced by the carbonate balance in the ocean."*

The analysis of the proposed statement (PS: 1) is not in accordance with the test instructions (TL: 1). Two types of chemical representations were used, namely phenomenology and process, but no relationship was found between the two (CU: 4). Although the first sentence is correct, the second sentence gives rise to a different interpretation of the phrase "availability of $CaCO_3$" because it does not show a relationship in the context of the previous sentence. This phrase can express a misunderstanding (CC: 3) that carbonate equilibrium is a source of $CaCO_3$ or $CaCO_3$ is produced from the sea.

| **Input:** → | **Process:** → | **Output:** |
|---|---|---|
| **1) The chemical problem is the conclusion of a chemistry article.**<br>**2) The problem is limited to the concept of chemical equilibrium in chemistry articles.** | **Find chemical objects with chemical characters that match the problem constraints (such as chemical formulas, chemical quantities, and chemical symbols).** | **Paraphrase the statement about the case of the chemical object.** |
| ***Initiation*** | *Metacognitive reading* — *Problem determination* — *Writing the problem* | *Termination* |

**Figure 2.** Pattern of the fair level in the chemistry problem-posing activity.

The fair level in the previous taxonomy (Sawuwu, 2018) signified that participant needed understanding of components in a problem. Figures 1 and 2 indicate similar output but this second pattern is just a paraphrase of information.

c. Lower intermediate

Three patterns of the chemical problem submission process were identified in the lower intermediate category as shown in Figure 3. Type A did not ask question sentences as shown in the following PC051 participant problem submission sheet.

Type A: *"Increased $CO_2$ in the atmosphere results in more $CO_2$ soluble in water. The increase in $CO_2$ are caused by many things such as global warming, dynamite fishing, and many more. This will destroy the carbonate balance causing the $CaCO_3$ to be unsaturated, causing algae lessening and coral reefs bleaching. Problems: (a) $CO_2$ is more soluble in water; (b) the greenhouse effect and global warming; (c) shifting of carbonate equilibrium."*

Type B: *"If there is more $CO_2$ in the atmosphere/unexpectedly then in what year will it not form in the polar regions? Coupled with other factors that further aggravate the marine ecosystem."*

Type C: *"Indeed, if you look at Indonesia as a country that has wide waters, wide seas. But the citizens themselves do not / less attention to the Indonesian sea. And it is undeniable that the whole world must emit large amounts of $CO_2$. Then, to overcome this, what should be done?"*

Even though Type A was only a sentence stating the initial state (TL: 1 and PS: 1), participants used two chemical representations (phenomenology and process) which were correlated. However, the participant misunderstood (CC: 3) that blasting fishing is a factor that destroys the carbonate balance and acidification that causes coral bleaching.

Types B and C ask single question sentences (PS: 3). Type B tends to ask as a formal action that does not need to be explained (TL: 2) and the answer can be found explicitly in the article, while type C tends to ask for contributions to the problems found (TL: 3). Examples of types B and C, respectively, are shown from the following CE042 and CE041 participant problem submission sheets.

Type C only uses a phenomenological representation (CU: 2), while type B uses two implicit phenomenological representations (CU: 3) (researchers perceive that the context of the second sentence is a unity or explanatory sentence from the main question sentence). But the biggest weakness of the two is that the question sentence is outside the concept of chemical equilibrium (CC: 2).

The lower intermediate level in the previous taxonomy (Sawuwu, 2018) signified that participant needed the understanding of chemistry in the text. Figure 3 indicates that participants in this level posed an out of context chemistry question regarding their curiosity or reflection of the text.

Type A

| | | | | |
|---|---|---|---|---|
| **Input:** 1) Chemical problems are the result of reflection on the content of chemistry articles. 2) The problem is limited to the concept of chemical equilibrium in chemistry articles. | **Process:** 1) Find the concept of chemical equilibrium which is characterized by chemical characters (such as chemical symbols, chemical formulas, and chemical quantities). 2) Explain the chemical concept in chronological order in the selected chemical representation. 3) Provide reflection results. | | | **Output:** Presenting the results of reflection and explanation of the chemical problems found. |
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

Type B

| | | | | |
|---|---|---|---|---|
| **Input:** A chemistry problem is a question about which the reader cannot find an explanation in the article. | **Process:** Finding the main phenomenological aspects of the discussion of the topic of chemistry articles. | | | **Output:** Inquiry questions whose answers can be found in chemistry articles. |
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

Type C

| | | | | |
|---|---|---|---|---|
| **Input:** A chemistry problem is a question about something that cannot be explained in the article according to the reader. | **Process:** 1) Reflect on the chemical problems found in the article. 2) Find the main source of the problem. 3) Directing questions to aspects that are suspected to be the source of the solution. | | | **Output:** Inquiry questions about contributing to problem solving without limiting the terms of the problem required |
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

**Figure 3.** Pattern of the lower intermediate level in the chemistry problem-posing activity

d. Intermediate

The intermediate level has two types of chemistry problem-posing skills as shown in Figure 4. Type A produces a statement of the initial state and its reflection but does not form a question (PS: 2), while type B has become a simple problem (PS: 5). To find out the difference, analyse the PC061 and PC036 participant chemistry problem submission sheets for the following types A and B.

Type A: *"The problem of the threat of coral reefs in aquatic ecosystems is not a trivial problem. Many other problems arise with this problem. Damage to coral reefs is certainly not only caused by the greenhouse effect or other global warming. However, direct human actions such as throwing garbage in the sea can also cause damage to coral reefs and other life in the sea. In addition, the way fishermen find fish using explosives is also a factor in the damage to coral reefs. Garbage that is wasted in the sea, especially plastic, is certainly difficult and takes a long time to be degraded, resulting in landfilling of garbage which even creates new substances that disrupt ecosystem processes in the sea. In this case, it is most likely that $CO_3^{2-}$ calcification is more difficult to occur so it is difficult to form coral reefs. Then, explosives that enter the sea leave chemical residues that can inhibit the formation of coral reefs. Therefore, there is a need for socialization and punishment for people who do not want to preserve the ecosystem in the sea."*

Type B: *"High $CO_2$ concentrations can destroy $CaCO_3$. This problem is avoided by reducing $CO_2$ production (mainly from human activities). However, marine plants are also capable of producing $O_2$. Then, what marine plants can reduce the concentration of $CO_2$ in the sea so as not to dissolve $CaCO_3$?"*

Type A uses two types of representation (phenomenology and process), but they are not complementary (CU: 4), while type B uses symbolic representations that support the phenomenological representation (CU: 5). The reflections made by type A on the problem headings found in the article are well packaged by connecting several appropriate concepts (TOR: 6). While type B makes a considerable error because of the desired final state the problem does not focus on the concept of chemical equilibrium (CC: 2). Based on these two types, the intermediate level still cannot distinguish between chemical problems and non-chemical problems.

Type A

| **Input:** | **Process:** | | | **Output:** |
|---|---|---|---|---|
| **Chemical problems are the result of reflection on the application of chemical equilibrium problems found in chemistry articles.** | **1) Find the problem of chemical equilibrium in chemistry articles.<br>2) Comparing the knowledge/experience you have about the problem.<br>3) Thinking of solutions to solve problems<br>4) Using phenomenological representation dominantly.** | | | **Make a description and view of the reader about the problem of chemical equilibrium without connecting some of the chemical representations used and propose solutions that do not focus on the chemical aspect.** |
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

Type B

| **Input:** | **Process:** | | | **Output:** |
|---|---|---|---|---|
| **Chemical problems are questions that contain reflections on chemical equilibrium problems found in the article.** | **1) Find the topic of chemistry problems in chemistry articles.<br>2) Comparing the knowledge possessed with the topic of the problem.<br>3) Focusing on the topic of the problem in one form of chemical representation.<br>4) Linking to non-chemical aspects.** | | | **Inquiry questions about the contribution to problem solving are limited to the terms of the problem but focus on one of the chemical representations.** |
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

**Figure 4.** Pattern of the intermediate level in the chemistry problem-posing activity.

The intermediate level in the previous taxonomy (Sawuwu, 2018) signified that participants did not understand the structure of a problem. From Figure 4, we find this level can arrange an initial state of the problem using a chemical representation without a complete final state (or well-structured problem).

e. Higher intermediate

The higher intermediate level also has two types of chemistry problem-posing skills with the final state in the form of a question sentence as shown in Figure 5. Generally, the achievement of all parameter levels 3. Submissions of type A and B problems can be seen in the following CE005 and PC022 participant problem submission sheets.

Type A: *"Carbon dioxide ($CO_2$) is a greenhouse gas that causes the acidification of seawater so that $CaCO_3$ cannot be formed because it shifts the equilibrium that occurs. What other substances besides $CO_2$ are able to shift the equilibrium? in other words it is more dangerous than $CO_2$."*

Type B: *"According to the prediction that there will be the year 2100, of course by looking at the facts that exist today, it is very possible if the prediction can come true. Furthermore, what can be done to prevent this? can the concept of chemical equilibrium be used to change the reaction equilibrium to shift to the right, so that the leaching of calcium carbonate can be reduced? On reaction: $CaCO_3(s) + CO_2(aq) + H_2O(l) \rightleftarrows Ca^{2+}(aq) + 2HCO_3^-(aq)$. Because the nature of the reaction is also reversible? Can it be?"*

Referring to the chemical information used, type B has a better chemical representation because it uses phenomenological, symbolic, and process representations (CU: 6). In type A, the two process phrases ("acidification process" and "equilibrium shift") become one clause that describes $CO_2$, so it is assessed using only one type of representation to explain the $CO_2$ (CU: 3). Types A and B cannot be classified as a problem because there are no discrepancies between the disclosed data.

Structurally, type A questions (PS: 3) are less complex than type B (PS: 4). However, the question word used in type A is a signifier for a higher level of thinking based on the previously created taxonomy (TL: 5). In addition, the chemical concept used by type A (CC: 5) is better than type B, it's just that there are concepts that require special explanation when participants use the clause "that substance is more dangerous than $CO_2$" (participants have prior knowledge that the level of reactivity of a substance indicates the level of danger of the effect of a substance). Type B erred in applying Le Chatelier's principle in preventing the loss of $CaCO_3$ in the given reaction (AC: 3).

Type A

| **Input:** → | **Process:** → | | | **Output:** |
|---|---|---|---|---|
| **Chemical problems are questions that contain chemical equilibrium problems found in chemistry articles and their solutions are speculative-manipulative.** | **1) Find the topic of chemistry problems in chemistry articles.<br>2) Comparing the knowledge possessed with the topic of the problem.<br>3) Predict solutions to problems that focus on certain chemical representations.** | | | **Explaining the initial state containing chemical problems and the final state in the form of questions confirming the prediction of a solution or predicting chemical aspects that can be used as a solution.** |
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

Type B

| **Input:** → | **Process:** → | | | **Output:** |
|---|---|---|---|---|
| **Chemical problems are questions that contain chemical equilibrium problems found in chemistry articles and the focus of their solutions.** | **1) Find the topic of chemical equilibrium problems in chemistry articles.<br>2) Analysing the specific chemical aspects that are the core of the chemical problem.<br>3) Comparing non-chemical knowledge possessed with understanding the problem topic.<br>4) Make general predictions about aspects that can lead to solutions.** | | | **Describes the initial state containing chemical problems and the final state in the form of problem-solving questions that focus on certain chemical representations.** |
| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |

**Figure 5.** Pattern of the higher intermediate level in the chemistry problem-posing activity.

The high intermediate level in the previous taxonomy (Sawuwu, 2018) signified that participants did not use chemical multirepresentations. From Figure 5, we find this level can arrange a problem with initial and final states using certain chemical representation with a directed operator (set solution limits).

f. Excellent

The excellent levels can already produce chemical problems but with some errors in the chemical concepts used. There are two types in this high level as shown in Figure 6. Examples of Types A and B are given in the following CE025 and CE022 participant chemistry problem submission sheets, respectively.

Type A: *"Carbonic acid from the reaction between $CO_2$ and water will release its proton to become bicarbonate ion reaction: $CO_2(aq) + H_2O(l) \rightleftarrows H_2CO_3(aq)$; $H_2CO_3(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + HCO_3^-(aq)$. The reaction for the formation of bicarbonate ions from the reversible conversion of bicarbonate ions: $HCO_3^- + H_2O \rightleftarrows H_3O^+ + CO_3^{2-}$. The addition of $HCO_3^-$ will produce a lot of $CO_3^{2-}$ ions which will cause the equilibrium of the formation of $CaCO_3(s)$ to shift towards $CO_3^{2-}$ so that $CaCO_3(s)$ becomes soluble. Are there other reagents that can bind the $HCO_3^-$ ion so that it doesn't react so that not much $CO_3^{2-}$ is formed? How to prevent $CO_2$ from reacting with $H_2O$ so that acidification does not occur in the sea?"*

Type B: *"$CO_2$ will protonate $H_2CO_3$ to $HCO_3^-$. Whereas $CO_3^{2-}$ is a rock-forming ($CaCO_3$) when reacted with $Ca^{2+}$. If the $CO_2$ content increases, the $HCO_3^-$ will also increase, resulting in a shortage of $CO_3^{2-}$ to form $CaCO_3$. So the carbonate equilibrium is unstable. Coral formation and $CO_2$ solubility are also affected by temperature. Can the excess $CO_2$ react with other compounds in seawater so that it does not protonate $H_2CO_3$? And also whether the equilibrium can be re-stabilized by the addition of $Ca^{2+}$ in seawater? Water pollution also affects the carbonate balance?*

Both types use a questioner signifier which is equivalent to thinking level 5 (TL: 5) in taxonomy and uses multiple chemical representations (CU: 6). Type A is classified as a simple problem (PS: 5) although the final state is composed of two questions centred on preventing seawater acidification. Type B is classified as a complex problem (PS: 6) because the final state contains two focus questions, namely protonated $CO_2$ and the effect of adding $Ca^{2+}$. However, these two types have quite serious chemical misconceptions (CC: 3). Type A is wrong in understanding the contents of the article that the decay of $CaCO_3$ is due to the increase in carbonate ions (supposedly due to the influence of excess hydronium ions from the acidification process), while Type B is wrong in the concept of protonation of $CO_2$.

Type A

| **Input:** → | **Process:** → | **Output:** |
|---|---|---|
| **Chemical problems are questions that contain chemical equilibrium problems found in chemistry articles and the focus of their solutions.** | **1) Find the topic of chemical equilibrium problems in chemistry articles.<br>2) Analysing the specific chemical aspects that are the core of the chemical problem.<br>3) Comparing non-chemical knowledge possessed with understanding the problem topic.<br>4) Assess other chemical and/or non-chemical factors that have the potential to limit solution submission.<br>5) Make general predictions about aspects that can lead to solutions.** | **Describe the initial state containing chemical problems and the final state in the form of problem solution questions based on several chemical representations.** |

| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |
|---|---|---|---|---|

Type B

| **Input:** → | **Process:** → | **Output:** |
|---|---|---|
| **Chemical problems are questions that contain the development of discussions about chemical equilibrium problems found in chemistry articles.** | **1) Find the topic of chemical equilibrium problems in chemistry articles.<br>2) Analysing the specific chemical aspects that are the core of the chemical problem.<br>3) Finding gaps between knowledge/experience, understanding of chemistry articles, and logical thinking on the relationship between information and mastered chemical concepts.<br>4) Make a synthesis of thinking from gap analysis and solutions that are thought on certain chemical representations.** | **Describe the initial state containing chemical problems and the final state in the form of problem-solving questions based on several chemical representations.** |

| ***Initiation*** | *Metacognitive reading* | *Problem determination* | *Writing the problem* | *Termination* |
|---|---|---|---|---|

**Figure 6.** Pattern of the excellent level in the chemistry problem-posing activity.

The excellent level in the previous taxonomy (Sawuwu, 2018) signified that participants did not monitor the limitation of problem context. This is difficult to observe because the monitoring aspect is not easily detected in text form. From Figure 6, we find this level can arrange a problem with initial and final states using chemical multirepresentation.

g. Outstanding

The results of the problem analysis for this outstanding level identify one type of chemistry problem-posing skills as shown in Figure 7. An example of this level is the CE013 participant chemistry problem submission.

*"With the increasing acidity of seawater, coral reef ecosystems will be disturbed due to the low level of $CaCO_3$ saturation caused by an increase in $CO_2$ concentration in the*

*atmosphere. In this case I think whether we can develop a solution such as other than reforestation (to reduce $CO_2$ levels in the atmosphere) or prohibition to exploit marine life on a large scale or prohibition to dispose of waste (household/industrial), I think that whether we can develop a biota that can produce a compound that is alkaline maybe for example like a biota that can produce ammonia (by symbiosis with other biota) is this possible? Or is there a biota that can produce protein (for example) and then in symbiosis with other biota will produce ammonia, but will the balance of the ocean be disturbed? I was wondering whether to throw away the shells (because I'm originally from the coast and I saw that people have a belief that by taking marine treasures (shellfish, fish, etc.) we must also return the rest to the sea) so whether to throw the shells back? to the sea will help the formation of $CaCO_3$ in the ocean?"*

It can be seen that the problem proposed is quite complex (PS: 6) because there are two focuses of the proposed problem, namely creative solutions to the acidification of seawater and confirmation of community myths in the application of the concept of chemical equilibrium. Although the signifier for the question words used is at level 5, the compound structure of the questions discusses the context relationships that are not discussed in the article with the participants' relevant thinking concepts (TL: 6). Participants only use a maximum of two types of chemical representations to explain chemical information (CU: 5). Because the question is a test of thinking results (marked by the clause "can we do it"), the assessment of the accuracy of chemical concepts is only up to the level of participants' ideas. The participant's idea was that acidification affects $CaCO_3$ saturation and this is overcome by linking multidisciplinary solutions (such as policy, acid-base theory, biosynthesis, and sociocultural) that shape socioscientific issues. The context of "ammonia" used by the participants is an example to explain the use of the acid-base theory. Although it has the potential to add new problems, the main idea assessed is the application of acid-base theory in the preparation of these problems.

<table>
<tr><td>Input:<br>Chemical problems are questions that arise from the results of critical reasoning about the application of chemical equilibrium problems that are limited by other chemical and non-chemical concepts.</td><td colspan="3">Process:<br>1) Find the topic of chemical equilibrium problems in chemistry articles.<br>2) Analyse problems on several chemical representations to find the source of the problem.<br>3) Comparing the knowledge/experience of readers to criticize the source of the problem.<br>4) Provide alternative solutions based on chemical problem constraints.<br>5) Assess the weakness of the solution and find further problems</td><td>Output:<br>Chronologically describes the initial state which contains the discrepancy between the article information, knowledge of chemical and non-chemical equilibrium, and the reader's experience of chemical problems and the final state in the form of questions regarding confirmation of solutions to problems based on several chemical representations.</td></tr>
<tr><td>Initiation</td><td>Metacognitive reading</td><td>Problem determination</td><td>Writing the problem</td><td>Termination</td></tr>
</table>

**Figure 7.** Pattern of the outstanding level in the chemistry problem-posing activity

The excellent level in the previous taxonomy (Sawuwu, 2018) signified that participant posed a problem significantly in metacognitive level. This requires more detailed explanation of the metacognitive level context. From Figure 7, we find the difference between the excellent and outstanding level. The outstanding level can arrange a problem with initial and final states using chemical multirepresentation and combining the relevant concepts related to the context.

### 3.2. Participants based on the chemistry problem-posing skills

The categorisation of chemistry problem-posing skills into seven levels is based on differences in input-process-output patterns in the chemistry problem-posing skills stages. Table 4 gives the information of participants' achievement in chemistry problem-posing skill. Based on the seven levels, there are four types of participants in the chemistry problem-posing.

**Table 4.** Participants' Achievement in Chemical Problem-posing Skill.

| The Sum of All Scores | Category | Total | Type | Accumulation |
|---|---|---|---|---|
| 22 ≤ total ≤ 24 | Outstanding | 09,2% | Metacognitive balance | 09,2% |
| 19 ≤ total ≤ 21 | Excellent | 15,8% | Metacognitive imbalance | 39,5% |
| 16 ≤ total ≤ 18 | Higher intermediate | 23,7% | | |
| 13 ≤ total ≤ 15 | Intermediate | 22,4% | Evaluation errors | 22,4% |
| 10 ≤ total ≤ 12 | Lower intermediate | 23,7% | Planning errors | 28,9% |
| 07 ≤ total ≤ 09 | Fair | 03,9% | | |
| 04 ≤ total ≤ 06 | Poor | 01,3% | | |

1) Participants with planning errors in chemistry problem-posing skills

Poor (Figure 1), fair (Figure 2), and lower intermediate (Figure 3) levels were owned by participants with the main problem on all parameter scores less than 3. These participants (28,9%) misunderstood the problem terms and chemical concept limits required in the test, which is used to formulate the purpose of submitting a chemistry problem. Failure to formulate this goal indicates a weak participant in the planning strategy which is the first point of determination in chemistry problem-posing skills (Schraw, et al., 2012; Veenman, 2012; Whitebread & Cardenas, 2012). The handling of this type of participant is through increasing the participants' declarative knowledge and procedural knowledge because both are precursors of planning strategies that form the basis for participants to construct reading plans and design what and how to propose problems to be done (Sperling, et al., 2004; Eldar, et al., 2012; Favieri, 2013).

2) Participants with evaluation errors in chemistry problem-posing skills

The intermediate level (Figure 4) is owned by participants with problems with CC scores less than 3 and CU and PS scores less than 4. These participants (22,4%) have not been able to distinguish between chemical questions and problems in sentence structure and chemical understanding. This shows that participants have problems in the components of metacognitive knowledge on task and strategy variables (Whitebread & Cardenas, 2012; Eldar, et al., 2012; Pintrich, 2002; Goh, 2008). These two variables interfere with the participants' metacognitive knowledge (Flavel, 1979) especially on conditional knowledge (Pintrich, 2002) which will affect the evaluation strategy (the fourth point of determination of the chemistry problem-posing skills).

3) Participants with metacognitive imbalance in chemistry problem-posing skills

The higher intermediate (Figure 5) and excellent (Figure 6) levels have reached 50% of the scores for each parameter, but there is no consistency between the parameters (the difference between the highest and lowest scores is more than one) which indicates an imbalance in the metacognitive components of the participants (39,5%). The imbalance of metacognitive components contributes to the quality of chemical problems (Veenman, 2012; Yilmaz-Tuzun & Topcu, 2010). The low TL indicates that participants are weak in metacognitive knowledge, which means that there is an error in their mindset (Krathwohl, 2002), performance (Pintrich, 2002), and understanding at the micro and macro levels of a material (Zohar & Dori, 2012). The low PS and CU indicate that participants lack in metacognitive strategies which means a lack of awareness and regulation of their cognitive strategies (Motague, 1997). The low CC indicates that participants have problems in metacognitive judgments, which means that there is no metacognitive knowledge control in metacognitive strategic execution (Ford & Yore, 2012).

4) Participants with metacognitive balance in chemistry problem-posing skills

The very high/outstanding level (Figure 7) shows that participants (9,2%) have been able to balance all metacognitive components in compiling chemistry problems which are indicated by parameter scores in the range of 5-6. Because metacognition is a process (Biggs, 1988), it can be said that participants with a high level of chemistry problem-posing skills also have good processing skills.

From this current study, a modification of signifiers of the taxonomy is proposed as shown in Table 5. This modification will help one to use the taxonomy and analyse the level of metacognition in chemistry problem-posing. These simpler signifiers will accelerate one in assessing the chemistry problem rather than use the four parameters of the taxonomy, even though it is not detailed in revealing the chemical understanding and concept accuracy. Based on the four types of participants in the chemistry problem-posing, the suggestions are also proposed to improve the skill for each level.

**Table 5.** Signified Update of The Chemical Problem-posing Skill.

| Category | Signified (Previous Study) | Modification of The Signifier (Current Study) | Improvement |
|---|---|---|---|
| **Outstanding** | The chemical problem is significantly in metacognitive level | arrange a problem with initial and final states using chemical multirepresentation and combining the relevant concepts related to the context | Expand other form of ill-structured chemistry problems |
| **Excellent** | The chemical problem is lack of monitoring | arrange a problem with initial and final states using chemical multirepresentation | Train the awareness and regulation to use the chemistry multirepresentation |
| **Higher intermediate** | The chemical problem is lack of the representations | arrange a problem with initial and final states using certain chemical representation with a directed operator (set solution limits) | |
| **Intermediate** | A problem and a question are indiscriminate | arrange an initial state of the problem using a chemical representation without a complete final state (or well-structured problem) | Train the conditional knowledge to evaluate the process |
| **Lower intermediate** | The in-context chemical understanding is required | posed an out-context chemistry question regarding their curiosity or reflection of the text | Train the declarative and procedural knowledge to make a systematic plan to read and arrange the chemistry problem |
| **Fair** | The understanding about the problem components is required | a paraphrase of information | |
| **Poor** | The task understanding is required | a repetition of information | |

Thus, the chemistry problem-posing skill is primarily formed by the ability to plan the process of getting the problem, to evaluate the feasibility of the chemistry problem, and to manage the chemistry multirepresentation composing the problem. By improving the specific ability, students will be able to reach the higher level in metacognition: planning the process through introducing composition of initial and final state of chemistry problems, evaluating the problem through applying conditional and strategic knowledge, and improving chemistry understanding in using multiple chemical representation from phenomenological, symbolic, and microscopic level.

## Conclusion

Chemistry problem-posing patterns found in this current study show the flow of the formulation of each problem. The input aspect for the formulation determines the process and the output result. The higher the level, the more complex and multiperspective determinations used for arranging a chemistry problem. The poor, fair, and low intermediate levels have planning problems and are unable to pose a simple chemical problem. The intermediate level had difficulty evaluating the chemistry problem, so that the problem posed were only an incomplete final state or a well-structured problem. The higher intermediate and excellent level had optional problem in strategic, knowledge, or judgement metacognitively, but they can produce a better chemistry problem with an initial state, final state, and operator. The outstanding level can produce a complex ill-structured chemistry problem that indicates a balance in strategy, knowledge, and metacognitive judgment.

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