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The Effect of Using a Guided Discovery Learning-Based Fundamental Chemical Laws Module on Students' Chemical Literacy Skills

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Abstract: Indonesian students' chemical literacy skills remain relatively low, due to limited instructional materials fostering students' active learning engagement. This research aims to analyze the effectiveness of a guided discovery learning (GDL)-based module on fundamental chemical laws on students' chemical literacy skills in Phase E at a senior high school (SMA-X) in Padang. This research is a quasi-experimental study with a nonequivalent control group design. The study involved 72 students, comprising 36 students in the experimental class and 36 students in the control class. The instrument was a modified chemical literacy test comprising eight essay questions, with validity and reliability assessed using the Ministep application with the Rasch Model approach. The data were analyzed using the N-Gain test, normality test, homogeneity test, hypothesis testing, and effect size analysis. The results showed that the N-Gain score for the experimental class (0.67) was higher than that of the control class (0.42). The normality test results indicated that the data were normally distributed, and the homogeneity of variance test showed that the data were homogeneous. The hypothesis test, conducted using Analysis of Covariance (ANCOVA) with a group significance level of 0.000 < 0.05, revealed a significant difference between the chemical literacy abilities of the experimental class and the control class. The module had a high (large) effect on improving students' chemical literacy skills, with an effect size (partial eta-squared) of 0.339. Thus, the GDL-based module on the fundamental chemical laws was significantly more effective in improving the chemical literacy skills of students in Phase E.

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INTRODUCTION

Students must have 21st-century competencies that focus on critical thinking, problem solving and applying knowledge in real-life contexts (Damme et al., 2023; Thornhill-Miller et al., 2023). In chemistry education, these demands are realized through chemical literacy, which requires an understanding of chemical concepts, connecting them to real-life phenomena, and using that knowledge to make science-based decisions (Zandroto & Sinaga, 2022). Chemical literacy is part of scientific literacy and is measured by the Programme for International Student Assessment (PISA). Therefore, scientific literacy scores can be used as a measure of students' chemical literacy (OECD, 2026).

However, based on empirical data, science literacy skills among Indonesian students are still facing difficulties. According to the results of the 2025 Programme for International Student Assessment (PISA), the mean science achievement score of Indonesia's 15 year old students were only 389 points, which is lower than the OECD average score of 482 points. Also, 63.2% of Indonesian students did not reach Level 2 in science literacy. This indicates that a large majority of Indonesian students are still unable to meet basic competencies in science (OECD, 2026).

This is supported by research showing that chemical literacy proficiency on the "explaining scientific phenomena" indicator reached only 43% and on the "using scientific evidence" indicator only 36%, thus falling into the low category (Zandroto & Sinaga, 2022). Moreover, the chemical literacy ability

of high school students regarding acid-base topic was not good enough since they only reach 56% average of total ability, which is categorized as low(Saputri et al., 2023).

These issues are not limited to the national level but also affect students in the city of Padang. From the literature review, it was found that there are no recent data on the achievements of high school students in Padang City in terms of their chemistry literacy results. However, there were several recent studies stating that the science literacy among students in Padang City was still at a low level (Yani & Akmam, 2025). This suggests that the issue of chemical literacy—as part of science literacy—remains an unresolved problem requiring further attention and the need for innovations in chemistry instruction (Mashami, 2025).

The low level of literacy made it difficult for students to comprehend chemistry content, especially the conceptual and quantitative aspects of the fundamental chemical laws (Tokgöz & Sarıkaya, 2025). Low levels of chemical literacy cause students to tend to merely memorize concepts without understanding their meaning and application (Melati et al., 2024; Rahmawati et al., 2024).

One contributing factor to this problem is the continued use of teacher-centered teaching methods, as well as a lack of instructional materials that encourage students' active engagement (Fitriani & Yerimadesi, 2022). Many improvement programs have been carried out with the development of learning tools in the form of e-module and interactive, effective, and appropriate learning modules. Previous research has developed a Guided Discovery Learning (GDL)-based module with a very high level of validity (Aiken's V = 0.925) and a practicality rate above 90% (Yuda & Yerimadesi, 2025). The result showed that the module is feasible in its design. However, there is insufficient evidence of validity and practicality to conclude whether the module is effective in improving students' chemical literacy. Hence, the purpose of this study was to examine the effectiveness of a GDL-based module on chemical literacy skills using a quasi-experimental study. The effectiveness of the module can be determined by examining the difference in learning outcomes between the experimental and control groups. The findings of this study would provide empirical evidence of the module's effectiveness in improving students' chemical literacy skills.

However, little study has been undertaken into the effectiveness of guided discovery learning based modules in teaching fundamental chemistry concepts to Phase E students. From a pedagogical perspective, GDL encourages active student engagement and helps students discover concepts through a guided learning process (Potier, 2023; Yerimadesi et al., 2023). However, the effectiveness of this approach needs to be empirically demonstrated in the context of teaching the basic laws of chemistry. Thus, this study sought to determine the significant effectiveness of a GDL module on the fundamental laws of chemistry in enhancing chemical literacy skills among Phase E high school students compared to the standard instructional materials used by the control group.

The study aimed to determine the effectiveness of a module designed to teach fundamental chemical laws using the GDL framework in increasing the chemical literacy of Phase E senior high school students.

METHOD

Research Type

This research used a quantitative approach in the form of a quasi-experimental design where a "nonequivalent control group design" was used, meaning there were two groups, the experimental group and the control group (Cham et al., 2024; Simesso, 2024). The experimental group received an intervention in the form of a GDL module that covered fundamental chemical laws proven to be effective. Meanwhile, the control group used learning modules from teaching materials already available at the school. These materials featured content presentations, sample problems, formulas, and practice problems designed to help students understand the concepts. However, these teaching materials are not specifically designed to support students in exploring the concept and building their chemical literacy skills by analyzing phenomena and applying concepts to everyday contexts. The control group will use existing learning modules. Population and Sample: All 10th-grade students in Phase E at a public high school in Padang during the 2025/2026 academic year became the population of this study. The sample was obtained using the cluster random sampling technique. This is a type of sampling where the samples are taken randomly from different groups (Cathrice, 2021).

Research Procedures

The study was conducted through three phases, namely the preparation phase, the implementation phase, and the completion phase. In the preparation phase, teaching-learning materials were prepared, such as learning modules and tools for research. Next, the implementation stage involved learning activities that applied the GDL model in accordance with the instructional modules. The final phase was collecting, processing, and analyzing the data acquired to evaluate the efficacy of the intervention on improving the chemical literacy skills of Phase E students at SMA-X.

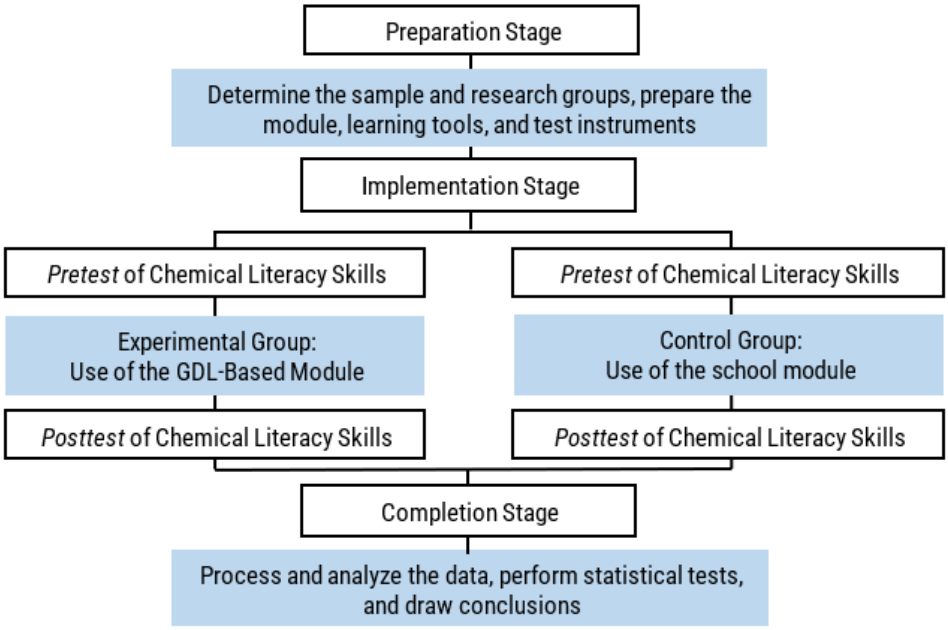


Figure 1. Research Procedure Flowchart

Population and Sample

The population in this study consisted of all tenth-grade students in Phase E at SMA-X Padang City in 2025/2026. The sampling technique was cluster random sampling (Ahmed, 2024; Cathrice, 2021). Two classes were chosen as a sample from all available classes. Each class had 36 students, divided into an experimental group and a control group.

Research Instruments

The instruments used were adapted from those developed by (Sartika & Yusmaita, 2020) for questions 1–6, which met the validity criteria, and modified from those developed by (Fauziyyah, 2023) for questions 7–8. The tool is composed of 8 open-ended questions aimed at assessing students' chemical literacy skills related to the topic 'Fundamental Chemical Laws'. The items 1 and 2 assess students' ability to apply and explain the Law of Conservation of Mass (Lavoisier) based on mass calculation and interpretation of data from reactions. Items 3 and 4 measure the ability to apply the Law of Definite Proportions (Proust) through determining the mass ratios of elements and explaining the concept of constant mass ratios. Furthermore, items 5 and 6 measure the ability to apply Dalton's Law of Multiple Proportions through comparing the masses of elements in compounds and interpreting calculation results. Item 7 tests the student's ability to use the fact that gas volumes are related in a chemical reaction. Item 8 tests their ability to apply Avogadro's Hypothesis to determine the gas volume from the number of particles at a given temperature and pressure. Overall, these eight items assess students' ability to apply chemical concepts, use calculation procedures, and interpret quantitative information in the context of chemical problems to improve students' chemical literacy (Vo et al., 2022). The instrument also measures procedural knowledge (K3) at the application (C3) cognitive level and covers the levels of scientific literacy, nominal scientific literacy, functional scientific literacy, and conceptual scientific literacy (Dunphy & Weisse, 2025; Sutiani et al., 2026; Zhang et al., 2026).

Pretests and posttests were administered to both groups using the same instrument. The use of

the same instrument was intended to ensure consistency in the aspects of ability being measured and to allow for a comparison of students' chemistry literacy abilities before and after the intervention. The potential for a testing effect in the form of increased student familiarity with the test items is recognized as a limitation of using the same instrument. To mitigate this potential effect, the tests were administered using consistent procedures and instructions, without providing feedback or answer keys after the pretest and before the posttest was administered.

The instrument was then validated to ensure it was valid and reliable for use in the study. Data analysis to determine the instrument's quality was performed using the Rasch Model with MINISTEP software. The Rasch Model was used to analyze the quality of the open-ended instrument. This allowed us to determine the validity, reliability, difficulty, and discrimination of each item (Hadi & Csíkos, 2026).

Data Analysis Techniques

In this study, a quantitative data analysis method was used. N-gain test, normality test, homogeneity test, hypothesis testing, and effect size test were used on the obtained data to determine how much students improved their chemical literacy skills through the learning activities. A pre-test was conducted to collect data on students' initial ability before the learning activities. After the learning activities, a post-test was conducted to assess students' final ability.

As both classes had different initial abilities, hypothesis testing was conducted using Analysis of Covariance (ANCOVA). This is to find out the effect of treatment given on student's learning outcome by taking into account the students initial ability (pretest). The statistical hypothesis used was:

$$H_0: \mu_1 \leq \mu_2$$
$$H_1: \mu_1 > \mu_2$$

Notes:

μ_1 = mean *posttest* of the experimental group

μ_2 = mean *posttest* of the control group

H_0 = There will be no significant increase in students' chemical literacy skills in the experimental class as opposed to the control class when taking into consideration students' initial abilities.

H_1 = There will be a significant increase in students' chemical literacy skills in the experimental class as opposed to the control class when taking into consideration students' initial abilities.

Decision criteria:

a. If the significance value (Sig.) is < 0,05, then H_1 is accepted.
b. If the significance value (Sig.) is > 0,05, then H_0 is accepted (Lüdtke & Robitzsch, 2025; Nayeri et al., 2023).

RESULT AND DISCUSSION

This study used quantitative data obtained by using pre-test and post-test. There were eight essay items in the chemical literacy instrument used in this study. There were two groups involved in this study which were the experimental group and the control group. Each group consisted of 36 students.

The results of test item analysis using the Rasch model, conducted with Ministep software, are shown below across four aspects: item validity, reliability, discriminant power, and difficulty level. The developed instrument was then validated by three validators using a scale of -1 to 1, where -1 indicates irrelevant or inappropriate, 0 indicates somewhat irrelevant or somewhat inappropriate, and 1 indicates relevant or appropriate (Rezigalla et al., 2024). The content validity results are presented in Table 1. CVR values of 0.93 and 0.96 indicate that all item sets meet the criteria for content validity. These results suggest that the test items are considered relevant for measuring the competencies targeted by the assessment.

Table 1. Results of Content Validity Test

Passage	Item	CVR	Criteria
1,2,3	1, 2, 3, 4, 5, 6	0,93	Valid
4,5	7, 8	0,96	Valid

The empirical validity of the data was examined using the Rasch model and the Minstep software.

The empirical validity was evaluated by considering the Outfit Mean Square (MNSQ), Outfit Z-Standard (ZSTD), and Point Measure Correlation (PT Corr) values (Abdulmajid & Khalid, 2024; Hadi & Csíkos, 2026). The results of the empirical validity analysis of the test items are shown in Table 2. All test items were deemed acceptable based on the criteria used in the analysis. Although item 3 had an MNSQ Outfit value of 1.83, the decision to accept it still had to be based on a combined evaluation of the three indicators and the established item-fit criteria.

Table 2. Result of Empirical Validity Test

Item	OUTFIT		PT Corr	Remarks
	MNSQ	ZSTD		
1	0,57	-1,59	0,58	Accepted
2	0,77	-0,92	0,46	Accepted
3	1,83	1,59	0,77	Accepted
4	1,00	0,12	0,77	Accepted
5	0,77	-0,33	0,84	Accepted
6	0,90	-0,22	0,77	Accepted
7	1,06	0,29	0,73	Accepted
8	0,88	-0,06	0,73	Accepted

Reliability of the instrument was checked by calculating person reliability, item reliability, and Cronbach's Alpha (KR-20). It showed that the test is reliable and that the item difficulty hierarchy has remained stable (Abdulmajid & Khalid, 2024; Hadi & Csíkos, 2026). The results of the item reliability analysis are shown in Table 3. The high person reliability coefficient (0.91) is combined with a high item reliability coefficient (0.92). This indicates that the instrument is highly reliable. The Cronbach's Alpha of 0.87 indicates that the instrument has good internal consistency. Overall, the instrument has sufficient reliability to measure students' ability.

Table 3. Result of Instrument Reliability Test

Aspects	Score	Remarks
Person Reliability	0,91	Very Good
Item Reliability	0,92	Very Good
Cronbach Alpha (KR-20)	0,87	Good

The discriminant validity was analyzed so that it could be determined how well each item was able to differentiate between students by ability (Stemler, 2021). The results of the item discrimination analysis are shown in Table 4. The analysis results show that item 5 has very good discriminating power, five items have good discriminating power, and two items have adequate discriminating power. These findings indicate that most items are effective in distinguishing students' ability levels.

Table 4. Result of Instrument Discrimination Test

Item	Remarks
5	Very Good
3, 4, 6, 7, 8	Good
1, 2	Fair

The item difficulty levels were analyzed using the Joint Maximum Likelihood Estimation (JMLE) measure in logit units, derived from Rasch modeling (Darman et al., 2024; Hadi & Csíkos, 2026). The results of the item difficulty analysis are presented in Table 5. The analysis results show that two items are classified as very difficult, two as moderate, three as easy, and one as very easy. This distribution illustrates the variation in the instrument's difficulty levels, although it still needs to be adjusted to align with the measurement objectives and the characteristics of students' abilities.

After the instrument's quality was deemed acceptable based on validity, reliability, discriminative power, and difficulty level, it was used to measure students' chemistry literacy in the experimental and control groups. The results of the chemical literacy skills are shown in Table 6.

Table 5. Result of Instrumen Difficulty Test

Item	JMLE Measure (logit)	Remarks
3	+2,38	Very Difficult
5	+2,20	Very Difficult
7	+0,83	Moderate
8	+0,41	Moderate
4	-1,22	Easy
1	-1,38	Easy
6	-1,38	Easy
2	-1,85	Very Easy

Table 6. Result of Chemical Literacy

Group	N	Pre-test	Post-test	N-Gain	Category
Control	36	14,5	50,5	0,42	Moderate
Experimental	36	26,2	75,9	0,67	Moderate

The mean pre-test and post-test scores resulted in increased scores. This indicates that both classes developed their chemical literacy skills. However, the experimental group showed greater improvement, with a higher score (Table 6). Both classes had moderate N-Gain scores. Despite both classes being in the same category, the experimental class's mean post-test score (75.9) was higher than the control class's (50.5). The experimental class also had a higher N-Gain score (0.67) compared with the control class (0.42). Overall, a GDL-based module was found to be more effective in improving students' chemical literacy within the experimental class.

The mean pre-test score for the experimental class was 26.2, compared with 14.5 for the control class (Table 6). This means that the two groups had different starting abilities. A hypothesis test was performed using Analysis of Covariance (ANCOVA) as the pre-test was used as a covariate in order to determine the effect of the treatment on chemical literacy (Muntholib et al., 2023; Nayeri et al., 2023).

In order to prove there was a significant difference between the two groups, the data analysis included a normality test, homogeneity test, hypothesis test, and effect size calculation. This was due to the results showing that the initial proficiency level of students within the experimental and control classes were not equivalent. The linearity and homogeneity of regression slopes were also tested to ensure ANCOVA could be used (Lüdtke & Robitzsch, 2025; Schwarz, 2025).

The results of the normality test regarding the distribution of data on chemical literacy skills for the classes included in the study are presented in Table 7.

Table 7. Results of the Normality Test for Chemical Literacy

Group	N	$D_{Calculated}$	D_{Table}	Decision
Control	36	0,19	0,22	Normal
Experimental	36	0,15	0,22	Normal

The result of the normality test for skill in literacy chemistry of the control group and experimental group showed that the t-value was less than the t-table value, which means that the data were normally distributed (Table 7). The result of the homogeneity test for chemical literacy between the control group and the experimental group showed that the F-value was less than the F-table value, which means that the data were homogeneous (Table 8).

Table 8. Result of the Homogeneity Test

Group	N	S^2	$F_{Calculated}$	F_{Table}	Description
Control	36	0,02	1,59	1,84	Homogeneous
Experimental	36	0,04			Homogeneous

Based on the analysis of linearity test results on the pretest and posttest data for both sample groups, it is known that there is a linear relationship and does not deviate from linearity between the

scores of the two sample groups. Thus, the research data fulfills the assumption of linearity and can proceed to perform the ANCOVA test.

Besides that, the result of the univariate test on the regression slope of the posttest data for both sample groups shows that the p-value is 0.055 > 0.05 for the interaction effect between Group and Pretest (Group Pretest). Hence, there is no significant interaction effect between group and pretest on the posttest score. Therefore, the assumption of homogeneity of regression slopes is fulfilled, and the ANCOVA test can be performed.

The results of the hypothesis test on chemical literacy ability in the sample classes are shown in Table 9. The results of the ANCOVA test with pretest as covariates. This table shows that the pretest covariate (0.002 < 0.05) had a significant effect on the posttest, since the value was significant. The group effect of 0.000 < 0.05 was also significant; therefore, we reject the null hypothesis (H0) and accept the alternative hypothesis (H1), indicating that there was a significant difference in chemical literacy abilities between the experimental and control groups after adjusting for the effect of the pretest. The adjusted R-squared value shows that 52.3% of the variance in the posttest can be explained by the model. This shows that there was a significant difference in chemical literacy skills between the experimental and control group. This indicates that the use of a GDL-based fundamental chemical laws module had an impact on improving students' chemical literacy skills compared to learning through commonly used teaching resources.

Table 9. Result of the Hypothesis Test for Chemical Literacy

	F	Sig.
Pretest	10,452	0,002
Group (Posttest)	35,340	0,000

R *Squared* = 0,536 (*Adjusted R Squared* = 0,523)

The results of the effect size test for chemical literacy skills in the sample classes can be seen in Table 10. As shown in Table 10, the partial Eta-squared value for the group was 0.339, indicating a large effect. This suggests that using the module had a large impact on students' chemical literacy skills. This is supported by research suggesting that the GDL approach is more effective at increasing learning outcomes and science literacy in chemistry when compared to conventional approaches (Yerimadesi et al., 2023). Therefore, the intervention (GDL-based fundamental chemical laws module) has a highly significant effect on students' chemical literacy skills compared to the control class.

Table 10. Results of the *Effect Size* Test for Chemical Literacy

	Partial Eta Squared (η^2)	Category
Pretest	0,132	Moderate
Group (Posttest)	0,339	Large

The GDL-based fundamental chemical laws module is designed to facilitate students' building of conceptual understanding through the scientific inquiry process. Activities in the basic chemistry module based on Guided Discovery Learning (GDL) demonstrate a connection to chemistry literacy indicators, namely explaining scientific phenomena, interpreting data, and using scientific evidence (Mabrouk, 2024; Qiao et al., 2024; Underwood et al., 2024). In the motivation and problem presentation stage (Figure 2, page 15), students are presented with the phenomenon of traffic congestion accompanied by molecular representations of CO and CO_2. This activity provides students with the opportunity to connect contextual phenomena with chemical representations, making it relevant to the indicator of explaining scientific phenomena. However, its effectiveness depends on students' ability to make these connections, rather than merely observing the images (Spitha et al., 2024).

In the data collection stage (page 17), students study information on the composition of sulfur dioxide (SO_2) and sulfur trioxide (SO_3), including the masses of sulfur and oxygen as well as their molecular representations. This information provides the basis for comparing the compositions of the two compounds and interpreting the quantitative relationships between their constituent elements. Next, during the data processing stage (page 18), students are asked to complete a table of element masses and determine the ratio of oxygen masses in the two compounds. This activity directly involves processing

quantitative data and using evidence in the form of mass ratios to support an understanding of Dalton's law of multiple proportions.

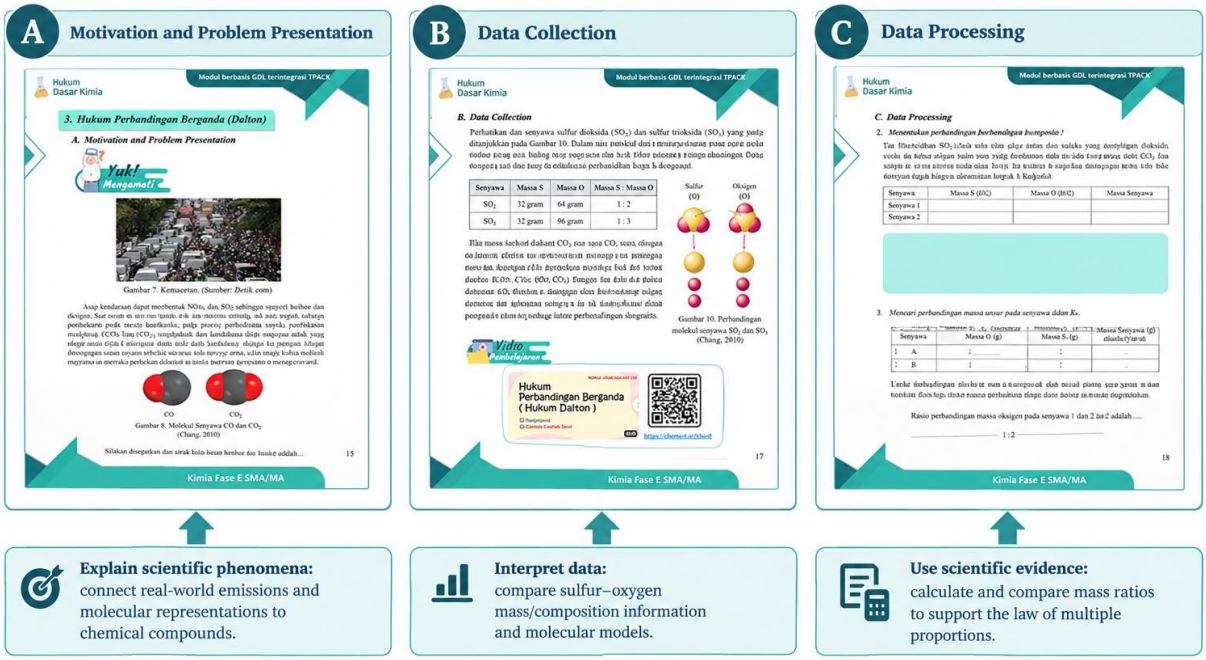


Figure 2. Demonstration of GDL Stages in Relation to Chemical Literacy Indicators

Overall, these three GDL-stage activities demonstrate how the module content facilitates learning aligned with the chemical literacy indicators. The problem-presentation stage supports the linking of phenomena to concepts, while data collection and processing provide students with opportunities to interpret information and use quantitative evidence. However, the presence of these activities does not in itself prove that students have mastered every indicator. Evidence of actual achievement must be based on student responses and the results of chemical literacy assessments. Furthermore, the relationship between the verification and conclusion-drawing stages and the three indicators needs to be explained using the module pages that directly contain these activities (Scharlott et al., 2024; Spitha et al., 2024; Stowe et al., 2021).

This improvement in chemical literacy is closely linked to the characteristics of the module, which was designed based on the GDL framework—namely, first, motivation and problem presentation; second, data collection; third, data processing; fourth, verification; and finally, drawing conclusions (Yerimadesi et al., 2023), as shown in Figure 2 (Yerimadesi et al., 2019). Based on the module's content, each learning stage is designed to actively engage students in discovering concepts. In the initial stage, students are presented with contextual phenomena that encourage them to identify problems and formulate hypotheses. Next, through data collection and processing activities, students are trained to analyze information and relate concepts to scientific evidence. The verification and conclusion-drawing stages strengthen students' ability to evaluate the validity of the hypotheses they have formulated. This active engagement is one of the strengths of the GDL model, as noted by (Yerimadesi et al., 2019), who state that this model possesses a high degree of validity and practicality because it optimally facilitates students' learning activities (Dražić & Devetak, 2025).

The application of GDL to the subject matter of the fundamental chemical laws provides students with the opportunity to build understanding through a gradual process of conceptual discovery. During the motivation and problem presentation stage, students are presented with contextual problems related to the fundamental chemical laws to spark curiosity, activate prior knowledge, and encourage students to make predictions about the problems presented (Yerimadesi et al., 2023). Presenting problem-based stimuli in the early stages is crucial in discovery learning because it directs students' attention toward the concepts to be discovered through the investigative process (Imroatus & Ikhsan, 2023). Next, during the data collection stage, students are actively engaged in identifying information and gathering relevant data

to address the problem. This activity reflects the characteristics of GDL, which positions students as the primary agents in acquiring and processing information through a guided inquiry process (Yerimadesi et al., 2023). The information obtained is then processed and analyzed during the data processing stage, enabling students to identify patterns, relationships, and chemical concepts from the available data. This process supports the development of conceptual understanding and the ability to apply chemical knowledge in solving problems. In the verification stage, students test their conjectures or hypotheses based on the data and concepts they have obtained, thereby verifying the validity of the concepts they have discovered. These verification activities are related to chemical literacy skills in using scientific evidence to support explanations and evaluate the information obtained (Ardyansyah & Rahayu, 2024; Wellhöfer & Lühken, 2022). Furthermore, the generalization stage provides students with the opportunity to draw conclusions and generalize the concepts they have discovered from various pieces of information and analysis. This process demonstrates that GDL learning not only guides students in obtaining answers but also builds connections among concepts, evidence, and phenomena, enabling the knowledge gained to be applied in broader contexts. In line with the framework of chemical literacy, conceptual mastery accompanied by the ability to connect chemical knowledge with phenomena and real-life contexts is a crucial component in developing chemical literacy (Sjöström et al., 2024; Wiyarsi et al., 2021). This development also aligns with the stages of literacy, in which literacy skills progress from conceptual recognition to conceptual understanding, procedural application of knowledge, and finally the ability to integrate various aspects of knowledge to understand phenomena more broadly (Sjöström et al., 2024). Thus, the series of GDL stages—ranging from problem presentation, information gathering, data processing, verification, to generalization—provides a systematic learning experience for students to build fundamental concepts of chemistry while developing the ability to use chemical knowledge to understand and explain scientific phenomena.

The patterns of student responses at each stage of the GDL process indicate that GDL-based modules are effective in facilitating the gradual development of students' chemical literacy, from the introduction of simple concepts to the integration of concepts and scientific evidence to draw conclusions. The higher the GDL stage students progress through, the better their achievement in chemical literacy (Sjöström et al., 2024).

This process relates to indicators of chemical literacy, such as explaining scientific phenomena, using scientific evidence, and interpreting data. The learning process using this module not only focuses on students mastering the concepts, but also focuses on developing their scientific thinking. This research proves that using the GDL model has a great effect in developing chemical literacy as students are trained in all three indicators (Hu et al., 2026; Warlinda et al., 2022; Wiyarsi et al., 2021).

The results of this study were in line with the constructivist theory that states students construct their own knowledge. Using the GDL model allows students to explore new concepts with guidance from teachers, thus making the learning more meaningful (Orosz et al., 2023; Partanen, 2023). This result was also supported by previous research showing that the GDL model has a high level of validity and practicality. The GDL model has also been proven effective in improving student learning outcomes and science literacy. Another study also found that the GDL model can develop students' critical thinking skills (Solikhah et al., 2025). Many studies have proven that the GDL model can increase chemical literacy as students are involved in the learning process (Orosz et al., 2023; Sjöström et al., 2024; Warlinda et al., 2022). Previous research also shows that modules based on the GDL model have a high level of validity, but their effectiveness has not been tested (Yuda & Yerimadesi, 2025). Hence, this research aims to demonstrate that using GDL-based modules in fundamental chemical laws can increase chemical literacy.

Several factors indicate that GDL-based modules are more effective. Firstly, students are more involved in the learning process. Secondly, students are developing critical and analytical thinking by exploring new concepts. Thirdly, new technologies are incorporated to help students understand abstract concepts (Alanazi, 2024; Aroch et al., 2024). Fourthly, the materials are contextual so students can connect the concepts to their everyday life. Lastly, the activities in the module are specific to the indicators of chemical literacy (Assi & Cohen, 2024; Zhang et al., 2023).

The findings of this research have theoretical and practical implications for developing chemistry literacy. Theoretically, the result supports the idea that using the GDL-based module grounded in

fundamental chemical laws can help students develop chemistry literacy. This is because the students' N-Gain score in the experimental class was higher (0.67) compared to the control class (0.42), and the ANCOVA also showed there was a significant improvement. This supports the use of GDL-based modules as an alternative way to increase chemistry literacy, specifically for the topics covered in this research.

In practice, chemistry teachers can implement GDL-based modules by guiding students to observe problems, analyze data, identify patterns, and draw conclusions based on fundamental chemical principles. Teachers act as facilitators who provide guidance throughout the discovery process, rather than merely conveying information. In curriculum design, these findings support the need to align instructional materials, learning activities, and assessments with the goal of developing chemistry literacy. Future module development can maintain the GDL stages while expanding the variety of contexts and exercises that apply concepts to everyday phenomena. However, these recommendations need to be further tested through research involving different schools, student characteristics, and a wider range of chemistry topics.

Although this study shows promising results, it is limited to a single school and material on the fundamental chemical laws. Therefore, generalizations of the findings should be made with caution. Future research is recommended to involve broader contexts and evaluate the consistency of the module's effectiveness across various chemistry topics and student characteristics.

CONCLUSION

This study has shown that the fundamental chemistry learning module using the GDL method is an effective way to improve chemical literacy skills among Phase E students compared with the school's learning resources. The experimental class had a higher N-Gain score (0.67) than the control class (0.42). However, it can be seen that both classes have moderate gains.

From the results obtained from the ANCOVA test, there is a significant difference in the chemical literacy skills between the two groups when pre-test scores are taken into account ((F=35.340); ($p<0.001$)). The partial eta squared value of 0.339 demonstrates that there is a large effect size. Therefore, using learning modules based on the GDL method has a significant impact on students' chemical literacy skills regarding fundamental chemical laws. However, this study was conducted at a single school and examined only one area of chemistry. To determine whether this finding can be applied more broadly, further testing should be conducted across a variety of schools and topics.

DECLARATION OF GENERATIVE AI

This article has been written using AI. QuillBot was used for paraphrasing, Grammarly for improving sentence structure, DeepL for translation assistance, and Turnitin for detecting plagiarism.

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REFERENCES

Abdulmajid, A. A., & Khalid, K. A. (2024). Using Rasch Analysis for Validation of Knowledge and Perception of Orthopedic Workplace-Based Assessment among Postgraduate Orthopedic Trainees' Questionnaire. *Journal of Pharmacy & Bioallied Sciences*, *16*(4), 126–129. https://doi.org/10.4103/jpbs.jpbs_629_24

Ahmed, S. K. (2024). How to choose a sampling technique and determine sample size for research: A simplified guide for researchers. *Oral Oncology Reports*, *12*, 100662. https://doi.org/https://doi.org/10.1016/j.oor.2024.100662

Alanazi, A. A. (2024). Effect of scaffolding strategies and guided discovery on higher-order thinking skills in physics education. *EURASIA Journal of Mathematics, Science and Technology Education*, *20*(9). https://doi.org/10.29333/ejmste/14980

Ardyansyah, A., & Rahayu, S. (2024). Technology-enhanced learning influence on chemical literacy : A systematic review. *Ecletica Quimica*, 1–9. https://doi.org/10.26850/1678-4618.eq.v49.2024.e1534

Aroch, I., Katchevich, D., & Blonder, R. (2024). Modes of technology integration in chemistry teaching: theory and practice. *Chemistry Education Research and Practice*, *25*(3), 843–861. https://doi.org/10.1039/d3rp00307h

Assi, A., & Cohen, A. (2024). Context-based learning in flipped middle school chemistry class. *International Journal of Science Education*, *0693*. https://doi.org/10.1080/09500693.2023.2250067

Cathrice, A. (2021). A brief guide to sampling in educational settings. *The Quantitative Methods for Psychology*, *17*(3), 286–298. https://doi.org/10.20982/tqmp.17.3.p286

Cham, H., Lee, H., & Migunov, I. (2024). Quasi-Experimental Designs for Causal Inference: An Overview. *Asia Pac Educ*, *25*(3), 611–627. https://doi.org/10.1007/s12564-024-09981-2.Quasi-Experimental

Damme, D. Van, Zahner, D., Cortellini, O., Dawber, T., & Rotholz, K. (2023). Assessing and developing critical-thinking skills in higher education. *European Journal of Education*, *58*(3), 369–386. https://doi.org/https://doi.org/10.1111/ejed.12563

Darman, D. R., Suhandi, A., Kaniawati, I., Samsudin, A., & Wibowo, F. C. (2024). Development and Validation of Scientific Inquiry Literacy Instrument (SILI) Using Rasch Measurement Model. In *Education Sciences* (Vol. 14, Issue 3, p. 322). https://doi.org/10.3390/educsci14030322

Dražić, A., & Devetak, I. (2025). Developing Chemical Literacy in Non-Formal Learning Environments: A Systematic Literature Review. *Acta Chim*, *72*, 145–153. https://doi.org/10.17344/acsi.2024.9108

Dunphy, S., & Weisse, Z. (2025). Replacement of Dimensional Analysis with Proportional Reasoning in Introductory Chemistry and Its Effects on Students' Chemistry Conceptual Understanding. *Journal of Chemical Education*, *102*(5), 1788–1802. https://doi.org/10.1021/acs.jchemed.4c01455

Fauziyyah, N. (2023). *Pengembangan instrumen tes literasi kimia berbasis konteks materi hukum gas*.

Fitriani, M., & Yerimadesi, Y. (2022). Pengaruh Penerapan Model Guided Discovery Learning Berbasis Lesson Study for Learning Community terhadap Hasil Belajar Siswa pada Materi Kesetimbangan Kimia di SMAN 5 Padang. *Jurnal Pendidikan Tambusai*, *6*(1), 7948–7954. https://doi.org/10.31004/jptam.v6i1.3652

Hadi, W., & Csíkos, C. (2026). Adapting and measuring mathematical problem-solving ability among secondary school students: a Rasch model analysis. *Frontiers in Education*, *Volume 11-2026*. https://doi.org/10.3389/feduc.2026.1900403

Hu, X., Wang, Z., Yao, Q., Lu, Y., Gou, C., Tong, K., & Li, L. (2026). Guided Discovery of H-Bond-Directed Reaction Divergence: A Teaching Lab on Anomalous Cyclization in Cyclic Sulfites. *Journal of Chemical Education*, *103*(3), 1491–1496. https://doi.org/10.1021/acs.jchemed.5c00884

Imroatus, S., & Ikhsan, J. (2023). *Enhancing Students ' Conceptual Understanding and Learning Independence in Chemical Equilibrium using E-Module Based Guided Discovery Learning*. *2*(December), 187–199.

Lüdtke, O., & Robitzsch, A. (2025). ANCOVA versus Change Score for the Analysis of Two-Wave Data. *The Journal of Experimental Education*, *93*(2), 363–395. https://doi.org/10.1080/00220973.2023.2246187

Mabrouk, P. A. (2024). Evaluating Threshold Concepts for Information Literacy in an Undergraduate Analytical Chemistry Literature Research Project. *Journal of Chemical Education*, *101*(3), 1002–1015. https://doi.org/10.1021/acs.jchemed.3c00944

Mashami, R. A. (2025). Social Sciences & Humanities Open Green chemistry and cultural wisdom : A pathway to improving scientific literacy among high school students. *Social Sciences & Humanities Open*, *11*(June), 101653. https://doi.org/10.1016/j.ssaho.2025.101653

Melati, H. A., Erlina, & Thongsan, N. C. (2024). *Analysis of Students' Chemical Literacy Skills with Scientific Information: Case Study During Covid-19*.

Muntholib, M., Anggraeni, D. P., & Zaroh, I. (2023). The Effect of POGIL instruction on Students' Chemical Literacy in Electrolyte and Nonelectrolyte Solution. *AIP Conference Proceedings*, *2569*.

Nayeri, N. D., Noodeh, F. A., Nia, H. S., Yaghoobzadeh, A., & Allen, K. A. (2023). *Statistical Procedures Used*

in Pretest-Posttest Control Group Design : A Review of Papers in Five Iranian Journals. *5*.
OECD. (2026). PISA 2025 Results (Volume I): Indonesia. In *PISA 2025 Results (Volume I)*. OECD. https://www.oecd.org/en/publications/pisa-2025-results-volume-i-country-notes_2d4ff9ea-en/indonesia_9c880f8a-en.html
Orosz, G., Németh, V., Kovács, L., Somogyi, Z., & Korom, E. (2023). Guided inquiry-based learning in secondary-school chemistry classes: a case study. *Chemistry Education Research and Practice*, *24*(1), 50–70. https://doi.org/10.1039/d2rp00110a
Partanen, L. J. (2023). A Guided Inquiry Learning Design for a Large-Scale Chemical Thermodynamics Laboratory Module. *Journal of Chemical Education*, *100*(1), 118–124. https://doi.org/10.1021/acs.jchemed.2c00387
Potier, D. N. (2023). The Use of Guided Inquiry to Support Student Progress and Engagement in High School Chemistry. *Journal of Chemical Education*, *100*(2), 1033–1038. https://doi.org/10.1021/acs.jchemed.2c00793
Qiao, C., Chen, Y., Guo, Q., & Yu, Y. (2024). Understanding science data literacy: a conceptual framework and assessment tool for college students majoring in STEM. *International Journal of STEM Education*, *11*(1), 25. https://doi.org/10.1186/s40594-024-00484-5
Rahmawati, Y., Erdawati, E., Ridwan, A., Veronica, N., & Hadiana, D. (2024). Developing Students' Chemical Literacy Through The Integration Of Dilemma Stories Into A STEAM Project On Petroleum Topic. *Journal of Technology and Science Education*, *14*(2), 376–392. https://doi.org/10.3926/jotse.2221
Rezigalla, A. A., Eleragi, A. M. E. S. A., Elhussein, A. B., Alfaifi, J., ALGhamdi, M. A., Al Ameer, A. Y., Yahia, A. I. O., Mohammed, O. A., & Adam, M. I. E. (2024). Item analysis: the impact of distractor efficiency on the difficulty index and discrimination power of multiple-choice items. *BMC Medical Education*, *24*(1), 445. https://doi.org/10.1186/s12909-024-05433-y
Saputri, E. N., Laksono, P. J., & Wigati, I. (2023). *Chemical Literacy Ability in Gender Perspective On Acid-Base Material*. *26*(1). https://doi.org/10.20961/paedagogia.v26i1.66009
Sartika, A. Y. M., & Yusmaita, E. (2020). Pengembangan instrumen tes literasi kimia materi hukum dasar kimia untuk siswa SMA fase E. *Jurnal Pendidikan Kimia Indonesia*, *4*(2), 55–66.
Scharlott, L. J., Rippey, D. W., Rosa, V., & Becker, N. M. (2024). Progression toward Causal Mechanistic Reasoning through Phenomenon-Based Learning in Introductory Chemistry. *Journal of Chemical Education*, *101*(3), 777–788. https://doi.org/10.1021/acs.jchemed.3c00517
Schwarz, W. (2025). The Ancova model for comparing two groups : a tutorial emphasizing statistical distribution theory. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2025.1600764
Simesso, M. D. (2024). The Contribution of Using Cooperative Learning Methods on Students ' Achievement and Retention in Secondary Schools during Chemistry Lesson. *Education Research International*, *2024*. https://doi.org/10.1155/2024/1830124
Sjöström, J., Yavuzkaya, M., Guerrero, G., & Eilks, I. (2024). Critical Chemical Literacy as a Main Goal of Chemistry Education Aiming for Climate Empowerment and Agency. *Journal of Chemical Education*. https://doi.org/10.1021/acs.jchemed.4c00452
Solikhah, S. A., Habiddin, H., Utomo, Y., & Munzil, M. (2025). Guided Discovery Learning in Chemical Bonding : An Examination of Students ' Critical Thinking Skills and Character Values. *Indonesian Journal of Educational Research and Review*, *8*, 92–101. https://doi.org/10.23887/ijerr.v8i1.83321
Spitha, N., Zhang, Y., Pazicni, S., Fullington, S. A., Morais, C., Rae Buchberger, A., & Doolittle, P. S. (2024). Supporting submicroscopic reasoning in students' explanations of absorption phenomena using a simulation-based activity. *Chemistry Education Research and Practice*, *25*(1), 133–150. https://doi.org/10.1039/d3rp00153a
Stemler, S. E. (2021). Rasch Measurement v . Item Response Theory : Knowing When to Cross the Line Rasch Measurement v . Item Response Theory : Knowing When to Cross the Line. *Practical Assessment, Research, and Evaluation*, *26*. https://doi.org/10.7275/v2gd-4441
Stowe, R. L., Scharlott, L. J., Ralph, V. R., Becker, N. M., & Cooper, M. M. (2021). You Are What You Assess: The Case for Emphasizing Chemistry on Chemistry Assessments. *Journal of Chemical Education*, *98*(8), 2490–2495. https://doi.org/10.1021/acs.jchemed.1c00532

Sutiani, A., Situmorang, M., Jahro, I. S., Purba, J., & Dibyantini, R. E. (2026). *Implementation of socio-scientific issue learning to promote chemical literacy as a strategy to achieve chemistry competency*.

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J.-M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. *Journal of Intelligence*, *11*(3). https://doi.org/10.3390/jintelligence11030054

Tokgöz, E. O., & Sarıkaya, M. (2025). Experimental Study on Eliminating Misconceptions Regarding the Law of Conservation of Mass in Chemical Reactions in Gifted Students. *Journal of Chemical Education*, *102*(6), 2268–2282. https://doi.org/10.1021/acs.jchemed.4c01285

Underwood, S. M., Swamy, U., Ramjattan, K., & Pliopa, A. R. (2024). Applying Chemistry Core Ideas to the Real-World: Implementing Student Projects to Help See the Bigger Picture. *Journal of Chemical Education*, *101*(11), 4643–4650. https://doi.org/10.1021/acs.jchemed.3c00995

Vo, K., Sarkar, M., White, P. J., & Yuriev, E. (2022). Problem solving in chemistry supported by metacognitive scaffolding: teaching associates' perspectives and practices. *Chemistry Education Research and Practice*, *23*(2), 436–451. https://doi.org/10.1039/d1rp00242b

Warlinda, Y. A., Yerimadesi, Y., Hardeli, H., & Andromeda, A. (2022). Implementation of Guided Discovery Learning Model with SETS Approach Assisted by E-Modul Chemistry on Scientific Literacy of Students. *Jurnal Penelitian Pendidikan IPA*, *8*(2), 507–514. https://doi.org/10.29303/jppipa.v8i2.1264

Wellhöfer, L., & Lühken, A. (2022). Information Is Experimental: A Qualitative Study of Students' Chemical Information Literacy in a Problem-Based Beginner Laboratory. *Journal of Chemical Education*, *99*(12), 4057–4067. https://doi.org/10.1021/acs.jchemed.2c00305

Wiyarsi, A., Prodjosantoso, A. K., & Nugraheni, A. R. E. (2021). Promoting Students' Scientific Habits of Mind and Chemical Literacy Using the Context of Socio-Scientific Issues on the Inquiry Learning. *Frontiers in Education*. https://doi.org/10.3389/feduc.2021.660495

Yani, S. R. F., & Akmam. (2025). Studi Pendahuluan Terhadap Kemampuan Literasi Sains Pada Pembelajaran Fisika Kelas Xi SMAN 4 Padang. *Jurnal Penelitian Guru Indonesia*, *5*, 3880–3889.

Yerimadesi, Y., Kiram, Y., Lufri, L., Festiyed, F., & Guspatni, G. (2019). Validity and practicality of guided discovery learning models for chemistry learning in senior high school. *Journal of Physics: Conference Series*, *1317*(1). https://doi.org/10.1088/1742-6596/1317/1/012149

Yerimadesi, Y., Warlinda, Y. A., Rosanna, D. L., Sakinah, M., Putri, E. J., Guspatni, G., & Andromeda, A. (2023). Guided discovery learning-based chemistry e-module and its effect on students' higher-order thinking skills. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 168–177. https://doi.org/10.15294/jpii.v12i1.42130

Yuda, S., & Yerimadesi. (2025). Development of a Basic Laws of Chemistry Module Based on TPACK Integrated Guided Discovery Learning for Phase E of Senior High School. *Edukimia*, *7*(1), 12–22. https://doi.org/10.24036/ekj.v7.i1.a572

Zandroto, A. H., & Sinaga, M. (2022). Analisis kemampuan literasi kimia siswa pada indikator menjelaskan fenomena ilmiah dan menggunakan bukti ilmiah. *Jurnal Pendidikan Dan Ilmu Kimia*, *6*(1), 30–38.

Zhang, L., Liu, X., & Feng, H. (2023). Development and validation of an instrument for assessing scientific literacy from junior to senior high school. *Disciplinary and Interdisciplinary Science Education Research*. https://doi.org/10.1186/s43031-023-00093-2

Zhang, L., Liu, X., Wu, J., He, X., Chen, R., & Kong, D. (2026). Development and Validation of an Instrument for Assessing Literacy-Oriented Chemistry Achievement for Grades 9 to 11 Students. *Journal of Chemical Education*, *103*(10), 5330–5343. https://doi.org/10.1021/acs.jchemed.6c00372