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Effectiveness of Atomic Structure Module Based on Guided Discovery Learning Integrated with TPACK Towards Improving Chemical Literacy Ability of Students of Phase E in High School

Efektivitas Modul Struktur Atom Berbasis Guided Discovery Learning Terintegrasi TPACK terhadap Peningkatan Kemampuan Literasi Kimia Peserta Didik Fase E di SMA

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Abstract

This study aimed to analyze the effectiveness of the atomic structure module based on guided discovery learning integrated with TPACK on improving the chemical literacy skills of phase E students in high school. The research applied the type of quasi-experiment with pretest-posttest control group design. The population includes phase E students of class X SMAN 1 Sungai Penuh who are studying chemistry in the 2024/2025 academic year, as many as seven classes. Samples were taken using a purposive sampling technique, and the experimental class X.D and control class X.F were selected. Chemical literacy test instrument in the form of essay questions. The data obtained were analyzed using the n-gain test and hypothesis testing with the 't' test. The results of data analysis obtained the n-gain value of the control class and experimental class, respectively, 0.20 in the low category and 0.35 in the medium category. The hypothesis test results obtained $t_{count} > t_{table}$, *which is 3.66 > 1.99 The chemical literacy ability of the experimental class is significantly higher than that of the control class. So the atomic structure module based on guided discovery learning integrated with TPACK effectively improves the chemical literacy skills of SMAN 1 Sungai Penuh phase E students.*

Keywords: *Module, atomic structure, guided discovery learning, TPACK, chemical literacy.*

Abstrak

Tujuan penelitian ini adalah untuk menganalisis efektivitas modul struktur atom berbasis *guided discovery learning* terintegrasi TPACK terhadap peningkatan kemampuan literasi kimia peserta didik fase E di SMA. Penelitian menerapkan jenis *quasi experiment* dengan *pretest posttest control group design*. Populasi meliputi peserta didik fase E kelas X SMAN 1 Sungai Penuh yang sedang mempelajari kimia tahun pelajaran 2024/2025 sebanyak tujuh kelas. Sampel diambil dengan Teknik *purposive sampling* dan terpilih kelas kelas eksperimen X.D serta kelas kontrol X.F. Intrument tes literasi kimia berupa soal essay. Data yang diperoleh dianalisis menggunakan uji n-gain serta uji hipotesis dengan uji t'. hasil analisis data didapatkan nilai n-gain kelas kontrol dan kelas eksperimen secara berturut-turut 0,20 kategori rendah dan 0,35 kategori sedang. Hasil uji hipotesis didapatkan $t_{hitung} > t_{tabel}$ yakni 3,66 > 1,99 maka kemampuan literasi kimia kelas eksperimen lebih tinggi secara signifikan daripada kelas kontrol. Sehingga dapat disimpulkan bahwa modul struktur atom berbasis *guided discovery learning* terintegrasi TPACK efektif terhadap peningkatan kemampuan literasi kimia peserta didik fase E di SMAN 1 Sungai Penuh.

Kata Kunci: modul, struktur atom, *guided discovery learning*, TPACK, literasi kimia.

1. Introduction

Education is a fundamental aspect in the development of high-quality human resources in the era of globalization. As times change, the competencies required of students are becoming increasingly complex, not only limited to conceptual mastery but also including scientific literacy skills, particularly chemical literacy (Rahmawati et al., 2020). Chemical literacy is crucial because it enables students to understand chemical phenomena in daily life and to make decisions based on sound scientific understanding (Junanto & Sartika, 2023; Artini & Wijaya, 2020; Rudibyani, 2020). Furthermore, chemical literacy supports the development of critical and analytical thinking skills, which are essential in many aspects of modern life, especially in the study of chemistry, which demands a deep understanding of concepts and their application in real-world contexts (Idrus & Rahmawati, 2024; Kumalasari & Pramono, 2024; Zakaria et al., 2021; Septiani et al., 2020).

Chemistry education in Indonesia continues to face challenges, particularly in enhancing students' chemical literacy. According to the 2022 Programme for International Student Assessment (PISA) report, Indonesia remains ranked near the bottom in science literacy, which includes chemical literacy (Taruklimbong & Murniarti, 2024; Dandulana et al., 2023; Jannah et al., 2019). These findings highlight significant gaps in the education system, particularly in science instruction such as chemistry. One key factor contributing to low chemical literacy is the lack of practical learning approaches rooted in a deep understanding of concepts (Yusmar & Fadilah, 2023; Maullidyawati & Hidayah, 2022; Pertiwi et al., 2022). Therefore, innovations in instructional methods are needed to enhance students' chemical literacy so that they are better prepared for both academic demands and real-life problem solving (Hartati, 2020). In addition, certain topics in chemistry, such as atomic structure, chemical bonding, and thermochemistry, require profound conceptual understanding, as they involve abstract ideas that call for strong critical and analytical thinking to be applied meaningfully in various contexts (Middlecamp & Kean, 2022).

One of the most conceptually demanding topics in chemistry is atomic structure. This subject is abstract and requires high-level thinking and well-developed chemical literacy skills for students to grasp it effectively (Handayani et al., 2021). Atomic structure serves as a foundational concept for understanding more advanced chemistry topics, including chemical bonding, reactions, and elemental properties. Poor comprehension of atomic structure can hinder students' ability to understand and apply other complex concepts.

Based on a questionnaire distributed to students at SMA Negeri 1 Sungai Penuh, 77% of 70 respondents who had studied atomic structure indicated that the topic was difficult. A separate survey conducted among four chemistry teachers at the same school revealed that they believe students struggle with atomic structure primarily due to the abstract nature of the concepts. According to the teachers, students’ chemical literacy in atomic structure was considered moderate by 75% and low by 25%. This demonstrates a clear need for interventions that assist students, particularly through the use of appropriate instructional models, learning materials, and pedagogical approaches.

One instructional model that has the potential to improve students' chemical literacy is the Guided Discovery Learning (GDL) model (Lase & Andromeda, 2023; Chaira & Hardeli, 2023; Rahmi & Fitriza, 2023; Darwis et al., 2019). GDL promotes student-led discovery of concepts under teacher guidance, making the learning process more structured and purposeful (Yerimadesi et al., 2019). It also encourages the development of critical, analytical, and problem-solving skills, all of which are necessary for understanding abstract chemistry topics (Halim &

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Wulandari, 2024; Jona et al., 2024; Hartini et al., 2023; Muntari et al., 2021). To implement such a model effectively, learning materials such as modules are required.

Modules are structured instructional materials aligned with curriculum standards, designed to be used independently to meet specific learning objectives (Gunawan & Yerimadesi, 2022; Rahayu, 2022). To make modules more relevant in modern classrooms, innovation is needed to integrate them with technology through the Technological Pedagogical and Content Knowledge (TPACK) approach. TPACK represents an educational innovation that aligns with technological advancements to help achieve learning outcomes by merging teacher expertise with digital tools.

The urgency of this research is further reinforced by the implementation of the Merdeka Curriculum, which emphasizes holistic student development and competency-based learning. This curriculum provides schools with the flexibility to adapt teaching strategies according to the needs and characteristics of their students (Rosa et al., 2024; Safitri et al., 2024; Idhartono et al., 2022). SMA Negeri 1 Sungai Penuh was selected as the research site because it has adopted the Merdeka Curriculum and possesses adequate facilities to implement the GDL model. Furthermore, based on preliminary observations, the school still lacks innovative learning strategies that effectively enhance students' chemical literacy, especially in mastering the complex concepts found in atomic structure.

Although numerous studies have investigated the application of GDL in chemistry education and have reported positive impacts on students' understanding and motivation (Weni & Yerimadesi, 2024; Ardila & Suryelita, 2023; Lase & Andromeda, 2023; Yani & Yerimadesi, 2023; Kartini et al., 2021; Darwis et al., 2019), research that specifically explores the effectiveness of an atomic structure module based on GDL and integrated with TPACK for improving the chemical literacy of Phase E students remains scarce. Therefore, this study is essential to bridge this research gap and provide scientific contributions toward developing more effective chemistry learning methods. Additionally, this research aims to evaluate the extent to which the GDL model can be effectively integrated with other instructional strategies to enhance students' chemical literacy.

In previous research, a GDL-based atomic structure module integrated with TPACK was developed and shown to be valid and practical, but its effectiveness has not yet been evaluated (Weni & Yerimadesi, 2024). Based on the above background, it is necessary to conduct a study titled "The Effectiveness of a Guided Discovery Learning-Based Atomic Structure Module Integrated with TPACK in Enhancing the Chemical Literacy of Phase E High School Students."

2. Literature Review

2.1 Guided Discovery Learning

Guided discovery learning is a learning model in which students are encouraged to investigate and discover concepts or principles independently, but still under the supervision and guidance of the teacher. This allows students to be actively involved in learning to understand the material more deeply (Aningsih & Wolosah, 2022). In this model, students explore phenomena or problems relevant to the material being taught. They collect information and data through observations and experiments, then analyze the results to find the necessary concepts (Vita et al., 2022; Zuriatni et al., 2019).

2.2 Effectiveness of Teaching Materials

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Effective in English, "effective" means successfully doing something with beneficial results. Effectiveness is defined as being effective or supporting a goal. Effectiveness is a measurement of achieving the goals decided upon in every action. Something is said to be effective if it achieves the goals determined (Hasanuddin et al., 2022).

Teachers and students utilize teaching materials to help sustain the learning process. Teaching materials contain material descriptions to facilitate understanding the material or learning objectives in the curriculum (Hasanudin et al., 2021). Students must achieve the learning objectives contained in the teaching materials. The effectiveness of teaching materials aims to measure the achievement of the learning objectives of the teaching materials. The effectiveness of teaching materials can be known through the difference between data before and after the use of teaching materials through initial tests and final tests.

2.3 Module

Modules include several learning activities to help students achieve specific goals (Nasution, 2011). Hamdani (2011) states modules are structured and printed learning tools. Modules include topics, methods, learning objectives, and guidelines for independent learning activities. In addition, modules provide learners with the opportunity to test themselves with exercises that have been provided in the module. Module is defined as a set of written materials that are designed and organized so that students can learn independently by being given instructions with language and patterns that are arranged, such as the presence of a teacher during learning, so that they can understand the concepts properly and clearly (Depdiknas, 2008).

2.4 Technological Pedagogical and Content Knowledge (TPACK)

TPACK is a theoretical framework combining technology with pedagogy to facilitate learners in acquiring specific knowledge through technology. TPACK shows the relationship between three aspects, namely Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK). The results of the combination of these 3 basic knowledge produce 4 new knowledge, including Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK), which must be mastered by teachers in learning. (Rahmadi, 2019) .

2.5 Science Literacy

Science literacy, in a broad sense, is an approach that is open, free from benchmarks, and highly tested, allowing teachers and students more freedom of scientific content and methodology. Science literacy refers to the ability to think critically in identifying problems, formulating hypotheses, and designing and conducting research (Hidayati & Julianto, 2020).

2.6 Chemical Literacy

Chemical literacy refers to an individual's ability to understand and use chemical concepts in everyday life. It includes mastery of basic chemical knowledge, the ability to analyze scientific information, and skills in applying chemical concepts to solve problems (Pratama et al., 2024). In the past five years, chemical literacy has become an important focus in science education, with various studies exploring ways to improve students' understanding of chemical concepts and their practical applications (Sjöström et al., 2024). The following is a framework of chemical literacy levels used:

a. Scientific illiteracy: Learners who do not respond to and relate to reasonable questions about science. At this level, learners do not have the vocabulary, concepts, context, or cognitive ability to identify scientific questions.
b. Nominal scientific literacy: At this level, learners recognize vocabulary or issues related to science but cannot explain them meaningfully. They only memorize the names of concepts and terms but cannot define them meaningfully.
c. Functional scientific literacy: learners can correctly define concepts they understand, but their understanding of them is still limited.
d. Conceptual scientific literacy: learners conceptually understand scientific concepts and relationships between concepts, scientific habits of mind, procedural skills, and understanding of scientific inquiry.
e. Multi-dimensional scientific literacy: requires the essential components of science and technology concepts from a philosophical and historical perspective and relates them to society and daily life.

3. Research Methods

This study is a continuation of previous developmental research, which resulted in the creation of a valid and practical Atomic Structure Module based on Guided Discovery Learning (Weni & Yerimadesi, 2024). The research was conducted at SMAN 1 Sungai Penuh from April to May 2025. It employed a quantitative approach with a quasi-experimental design. The population comprised Phase E students of Class X at SMAN 1 Sungai Penuh who were enrolled in chemistry during the 2024/2025 academic year, totaling seven classes. The sample was selected using purposive sampling, as it was based on specific considerations. The sampled classes were chosen based on the similarity of their average academic performance, ensuring that their academic abilities were relatively equivalent. This was done to minimize bias due to differences in students' prior knowledge, thereby allowing the treatment effect to be measured more objectively. The selected samples were Class X-D as the experimental group and Class X-F as the control group.

During the learning implementation, the experimental class was taught using a Guided Discovery Learning model integrated with TPACK, while the control class received instruction using the standard teaching materials commonly used at school. Both classes were administered pretests and posttests to determine whether there was a significant difference in learning outcomes between the two groups. The test instrument was adopted from chemical literacy questions developed by Putri and Yusmaita (2024). The questions were subsequently revised and retested to yield a final test in the form of an essay consisting of nine items that were valid, reliable, and had satisfactory discriminating power and difficulty indices.

The independent variable in this study was the Atomic Structure Module based on Guided Discovery Learning integrated with TPACK, while the dependent variable was students' chemical literacy, as reflected in the chemical literacy scores derived from pretest and posttest results. Data analysis included calculating normalized gain (n-gain), as well as conducting normality tests, homogeneity tests, and hypothesis testing.

4. Results and Discussion

4.1. Research Results

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4.1.1. Results of Chemical Literacy Ability

The results of the students' chemical literacy skills are obtained from the n-gain value. The average n-gain value was analyzed from pretest and posttest data. The results obtained a higher n-gain in the experimental class than the control class. The n-gain data is shown in Table 1.

Table.1. N-Gain Test Results of Chemical Literacy of Sample Classes

Class	N	Pretest	Posttest	N-Gain	Category
Control	36	52,9	62,4	0,20	Low
Experiment	36	53,3	70,5	0,35	Medium

4.1.2. Normality Test

Statistical tests prove the difference between the two sample classes through normality tests. This normality test aims to see whether the research data obtained is normally distributed. The normality test results using Kolmogorov-Smirnov obtained the D_{count} control class and experimental class, which are 0.1214 and 0.1881, respectively, smaller than the D_{table}, which is 0.2267, so the data is normally distributed. The normality test data is shown in Table 2.

Table.2. Normality Test Results of Chemical Literacy

Class	N	D_{count}	D_{table}	Description
Control	36	0,1214	0,2267	Low
Experiment	36	0,1881	0,2267	Medium

4.1.3. Homogeneity Test

Homogeneity test analysis ensures that the data variance between the experimental class and the control class is homogeneous so that the appropriate statistical test can be used for hypothesis testing. Based on the data from the homogeneity test results, F_{count} 2.4748 greater than F_{table}, which is 1.8400, so the data is not homogeneous. Then, to test the hypothesis, t' is used. Homogeneity test data are shown in Table 3.

Table.3. Homogeneity Test Results of Chemical Literacy

Class	N	S^2	F_{count}	F_{table}	Description
Experiment	36	0,0404	2,4748	1,8400	Not Homogeneous
Control	36	0,0163			

4.1.4. Hypothesis Test

The results of hypothesis testing based on both normality and homogeneity of data were then used to carry out hypothesis testing using the 't' test. Obtained $t_{count} > t_{table}$, where H_0 is rejected and H_1 is accepted. The results are shown in Table 4.

Table.4. Hasil Uji Hipotesis Literasi Kimia

Class	t_{count}	t_{table}	Description
Experiment Control	3,66	1,99	H_0 rejected H_1 accepted

Students' chemical literacy skills are seen through the achievement of learning objectives. For example, the achievement of learning objectives to determine the number of particles that make up the atom based on the atomic number and mass number and distinguish isotopes, isobars, and isotones is shown by the' ability to answer questions in the module, as shown in Figure 1.

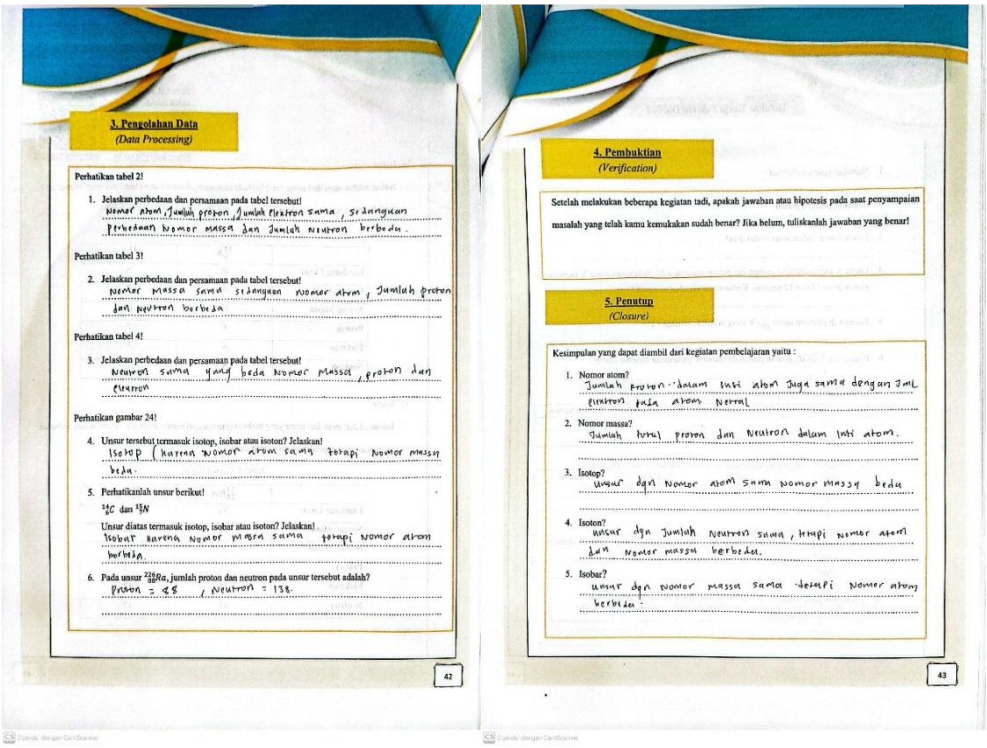

Figure.1. Example of Students' Answers to the Module

4.2. Discussion

Tables 1, 2, 3, and 4 illustrate the effectiveness of the Guided Discovery Learning (GDL)-based atomic structure module integrated with TPACK in enhancing students' chemical literacy. Table 1 shows an improvement in chemical literacy in both the control and experimental groups. However, the normalized gain (n-gain) in the control group falls under the "low" category, whereas in the experimental group, it is categorized as "moderate." This indicates that the experimental group's n-gain is higher than that of the control group. Therefore, the implementation of the GDL-based atomic structure module integrated with TPACK can enhance students' chemical literacy.

Tables 2 and 3 present statistical evidence of the differences between the two groups, starting with a normality test to determine whether the data were normally distributed. Based on the Kolmogorov-Smirnov test, the D_{count} values for the control and experimental classes were 0.1214 and 0.1881, respectively, both smaller than the D_{table} value of 0.2267, indicating that the data are normally distributed. A homogeneity test was then conducted to assess whether the variances between the two groups were equal. The results showed that the F_{count} value was 2.4748, which is greater than the F_{table} value of 1.8400, meaning the data are not homogeneous. Therefore, hypothesis testing was conducted using a modified t-test that accounts for unequal variances.

The results presented in Table 4 show a significant difference between the control and experimental groups. The t_{count} value exceeded the t_{table} value, indicating that the research hypothesis is accepted. This confirms that the GDL-based atomic structure module integrated with TPACK is effective in improving students' chemical literacy.

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The module includes subject matter, learning activities, worksheets, and assessments. For instance, as illustrated in Figure 1, the module includes questions that promote the development of chemical literacy. In this example, students are asked to analyze data regarding atomic number, mass number, and the number of subatomic particles to classify elements as isotopes, isobars, or isotones. This task requires students to process numerical data, draw conclusions based on chemical principles, and provide scientific reasoning. Such activities foster chemical literacy by engaging students in data interpretation, scientific reasoning, and science communication, all skills essential for real-world scientific application.

The responses shown in Figure 1 significantly contribute to students' chemical literacy. In this section, students are guided to analyze a table containing atomic number, mass number, and the number of protons, neutrons, and electrons for various elements. They are then asked to classify the elements as isotopes, isobars, or isotones. This task exemplifies chemical literacy practice as it combines conceptual understanding, data interpretation, and evidence-based reasoning (Imansari, 2018). For example, identifying ^{23}Na and ^{24}Mg as isotones, based on their shared neutron count despite being different elements, demonstrates students' ability to analyze and evaluate scientific information. The activity also trains science communication skills, as students must logically and scientifically explain their reasoning, which is a key component of chemical literacy.

Based on the responses illustrated in Figure 1, students demonstrated their ability to analyze numerical data and correctly classify elements as isotopes, isobars, or isotones. Therefore, the use of the GDL-based atomic structure module integrated with TPACK contributes to improving chemical literacy.

This module consistently applies the GDL model throughout its learning activities. The GDL model is effective in enhancing students' chemical literacy, as supported by previous studies. For example, Darwis et al. (2019) found that GDL positively impacts students' chemical literacy. Warlinda et al. (2022) also found that GDL significantly improved students' science literacy when applied with the SETS approach. Yerimadesi et al. (2019) showed that the GDL model effectively enhances students' critical thinking and learning outcomes.

The GDL allows students to independently discover concepts under teacher guidance, resulting in a more systematic and structured learning process (Yerimadesi et al., 2019). It also promotes the development of critical thinking, analytical skills, and problem-solving abilities, especially in grasping abstract chemistry concepts (Halim & Wulandari, 2024; Hartini et al., 2023; Jona et al., 2024; Muntari et al., 2021). Additional studies have demonstrated that GDL improves conceptual understanding, critical thinking, and student motivation in science learning (Muhali et al., 2021). Learners using the GDL module benefit from structured guidance through the GDL syntax, which facilitates conceptual discovery.

The GDL-based atomic structure module integrated with TPACK includes reading texts, images, videos, and audio components. The TPACK component is represented by QR codes that link to supporting multimedia resources, such as videos or audio, to accommodate differentiated instruction. The application of the GDL model in each learning activity represents the pedagogical aspect, while the atomic structure content represents the content knowledge component.

However, one limitation of using the GDL-based atomic structure module integrated with TPACK is the occasional difficulty in scanning QR codes containing video or audio. Sometimes, these codes cannot be scanned properly, causing confusion among students. They may need to attempt multiple scans before successfully accessing the content. To address this issue, it is recommended that the QR code surface be kept clean and undamaged. Additionally, users should try scanning from different angles or distances and ensure adequate lighting for optimal QR code recognition.

5. Conclusion

Based on the results of the study, it can be concluded that the Guided Discovery Learning-based Atomic Structure Module integrated with TPACK is effective in improving students' chemical literacy skills. This effectiveness is demonstrated by the significant increase in posttest scores of students in the experimental class compared to the control class. The integration of Guided Discovery Learning with TPACK allows students to be more actively involved in the learning process, develop higher-order thinking skills, and connect abstract chemical concepts with real-life contexts through appropriate use of technology. These findings support the importance of using innovative and student-centered learning models in chemistry education. Therefore, it is recommended for teachers to apply and further develop this module in classroom instruction to enhance student engagement and understanding. Future research is suggested to explore the use of similar modules on other chemistry topics or in different educational phases to broaden the scope and sustainability of its impact.

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