Interactive Electronic Student Worksheet to Improve Student Learning Outcomes in Atomic Structure Material

Muhammad Husein Ashari[1*]; Sukarmin[2]

[1,2]*Department of Chemistry Education, Universitas Negeri Surabaya, Indonesia*
[1*]*Corresponding Email: muhammadhusein.21047@mhs.unesa.ac.id*

Article History:
Received: Jun 16, 2025
Revised: Aug 13, 2025
Accepted: Dec 31, 2025
Online First: Jan 20, 2026

Keywords:
Atomic Structure,
e-LKPD,
Learning Outcomes.

Kata Kunci:
e-LKPD,
Learning Outcomes,
Struktur Atom.

How to cite:
Ashari, M. H., & Sukarmin. (2026). Interactive Electronic Student Worksheet to Improve Student Learning Outcomes in Atomic Structure Material. *Edunesia : Jurnal Ilmiah Pendidikan, 7*(1), 397-412.

Abstract: This study developed an interactive electronic student worksheet (e-LKPD) to improve learning outcomes on atomic structure using the Lee & Owen R&D model. The product was tested with 23 tenth-grade students at SMAN 1 Sambit and evaluated for validity, practicality, and effectiveness. Expert validation from two chemistry lecturers and one teacher confirmed strong content and construct validity, with modal scores of 3. In terms of practicality, 94.10% of students responded positively, and 91.11% of observed activities were relevant. Effectiveness was demonstrated through learning gains: 16 students achieved high n-gain scores (≥0.7) and 7 students achieved moderate gains (0.3–0.7). These findings indicate that the interactive e-LKPD is not only valid and practical but also highly applicable in classroom settings. Its digital, interactive format supports active learning and helps students grasp abstract scientific concepts more easily. The results underscore the potential of e-LKPD as an innovative tool in science education, particularly in facilitating student engagement and conceptual understanding. This Research contributes to the development of technology-based learning resources aligned with 21st-century educational needs.

Abstrak: Penelitian ini mengembangkan Lembar Kerja Peserta Didik Elektronik Interaktif (e-LKPD) untuk meningkatkan hasil belajar pada materi struktur atom dengan menggunakan model penelitian dan pengembangan Lee & Owen. Produk diuji pada 23 siswa kelas X di SMAN 1 Sambit dan dievaluasi dari aspek validitas, kepraktisan, dan efektivitas. Validitas dikonfirmasi oleh dua dosen kimia dan satu guru kimia, yang memberikan skor modal 3 untuk validitas isi dan konstruk. Dari segi kepraktisan, 94,10% siswa memberikan respons positif, dan 91,11% aktivitas siswa selama implementasi tergolong relevan. Efektivitas dibuktikan melalui peningkatan hasil belajar: 16 siswa mencapai skor *n-gain* tinggi (≥0,7), dan 7 siswa menunjukkan peningkatan sedang (0,3–0,7). Temuan ini menunjukkan bahwa e-LKPD interaktif tidak hanya valid dan efektif, tetapi juga sangat aplikatif dalam konteks pembelajaran di kelas. Format digital dan interaktifnya mendorong pembelajaran aktif serta membantu siswa memahami konsep-konsep abstrak secara lebih mudah. Penelitian ini menegaskan potensi e-LKPD sebagai alat inovatif dalam pendidikan sains, khususnya dalam meningkatkan keterlibatan dan pemahaman konsep siswa. Dengan demikian, e-LKPD ini memberikan kontribusi nyata terhadap pengembangan sumber belajar berbasis teknologi yang selaras dengan kebutuhan pendidikan abad ke-21.

https://doi.org/10.51276/edu.v7i1.1382

A. Introduction

In the current era of globalization and rapid advancements in information technology, education plays a crucial role in preparing younger generations to face future challenges (Melliana & Diana, 2024). One of the most essential aspects of education lies in how learning materials are delivered, not only informatively but also engagingly and meaningfully to students (Apriani et al., 2024). In science education, particularly in chemistry, effective instructional strategies are needed to facilitate students' understanding of complex concepts while fostering higher-order thinking skills. Chemistry is a scientific discipline that examines the properties, composition, and structure of matter, as well as the energy involved in chemical changes (Rocke, 2020). At the same time, chemistry explores phenomena associated with transformations of matter, many of which involve abstract concepts and theoretical representations that cannot be directly observed at the macroscopic level (Rachmawati & Sukarmin, 2022).

One of the fundamental topics in chemistry learning is atomic structure (Nirmalasari, 2020). Atomic structure is classified as a basic yet essential component of chemistry education, encompassing theories of atomic development, the structure of atoms including protons, electrons, and neutrons, electron configuration, and the classification of elements in the form of isotopes, isotones, and isobars (Mufida et al., 2022). Although chemistry is deeply embedded in everyday life, many of its core concepts, particularly those related to atomic and molecular structures, are inherently abstract and cannot be directly observed, such as interactions among atoms, molecules, and ions (Nurmasita et al., 2023; Lestari & Yerimadesi, 2024). As a result, students often struggle to form accurate mental representations of these concepts, which negatively affects their conceptual understanding and problem-solving abilities.

Numerous empirical studies have documented persistent learning difficulties in atomic structure materials at the senior high school level. Saleh et al (2022) reported that atomic structure is one of the most abstract and challenging topics in chemistry for students to comprehend. Similarly, Afrianis & Ningsih (2022), in their study of learning difficulties among students at SMAN 12 Pekanbaru, found that 74.91% of students experienced difficulties with calculation-based questions, while 59.73% struggled with conceptual questions related to atomic structure. These difficulties are reflected in low learning achievement levels. Mampate (2020) reported that only 45% of students met the minimum mastery criterion, while Mawarni (2018) found that approximately 80% failed to achieve the required mastery level in atomic structure assessments. These findings suggest that students' understanding of atomic structure remains limited and that their problem-solving skills in this topic remain relatively underdeveloped.

One contributing factor to these learning challenges is the continued reliance on traditional instructional approaches, such as lecture-based teaching and textbook-centered learning, which are still widely practiced in Indonesian chemistry classrooms. While such methods are efficient for delivering information, they often position students as passive recipients of knowledge, thereby limiting active engagement and deeper conceptual

https://doi.org/10.51276/edu.v7i1.1382

understanding, particularly when dealing with abstract topics such as atomic structure. Almarzuqi & Mat (2024) found that students taught predominantly through lectures tend to demonstrate lower levels of critical thinking and problem-solving skills. In a similar vein, Cahyana et al (2019) argued that learning environments that rely heavily on textual explanations fail to connect chemical concepts with real-life contexts, resulting in poor knowledge retention and limited ability to apply concepts meaningfully.

Empirical evidence increasingly supports the need for interactive and student-centered learning approaches in chemistry education. Ayob et al (2023) demonstrated that students who learned through interactive instructional strategies achieved significantly better learning outcomes than those taught using traditional methods. Their findings emphasize that abstract chemistry topics require instructional tools that go beyond verbal explanations and static representations, incorporating active learning and visualization to support conceptual understanding. Consequently, the integration of interactive digital media, such as electronic student worksheets (e-LKPD), has emerged as a promising innovation to enhance student engagement, conceptual understanding, and learning outcomes in chemistry learning contexts.

Learning outcomes can be further improved through contextual learning approaches that connect chemical concepts with real-world problems and environmental phenomena. One instructional model that supports this approach is Problem-Based Learning (PBL), which emphasizes learning through the exploration and resolution of authentic problems (Ayunda et al., 2023). PBL encourages students to actively construct knowledge, collaborate with peers, and develop critical thinking and problem-solving skills. Previous studies have shown that the PBL model can be effectively combined with e-LKPD to improve students' learning outcomes (Sari et al., 2024). Interactive learning models such as e-LKPD allow students to engage more deeply in the learning process, thereby enhancing motivation and conceptual understanding (Juniarni et al., 2019). These instructional approaches are strongly grounded in constructivist learning theory, which posits that learners actively construct knowledge through interaction with their environment. Piaget emphasized the role of active cognitive engagement in knowledge construction, while Vygotsky highlighted the importance of social interaction and scaffolding in facilitating learning (Hergenhahn & Olson, 2008).

As an interactive digital learning medium, e-LKPD integrates multimedia elements such as videos, audio, images, and hyperlinks to create richer and more meaningful learning experiences. e-LKPD functions as an electronic worksheet that students complete digitally within a structured timeframe, allowing for continuous interaction and feedback (Lathifah et al., 2021). Interactive e-LKPD can be developed using web-based platforms such as Liveworksheets, which provide various editing features, including the integration of multimedia content such as videos, audio, and images (Prasetyo & Novita, 2023). Moreover, Liveworksheets-based e-LKPD can be easily accessed on smartphones or laptops without requiring additional applications, making it a practical and accessible learning medium across diverse classroom settings (Yuliana et al., 2023).

https://doi.org/10.51276/edu.v7i1.1382

The integration of the Problem-Based Learning model into interactive e-LKPD further enhances its pedagogical potential. PBL supports the development of critical thinking, communication, and problem-solving skills while enabling students to apply theoretical knowledge to real-life situations (Ayunda et al., 2023). In chemistry education, PBL has been shown to improve students' conceptual understanding and reasoning abilities. For example, Saleh et al (2022) found that students who learned atomic structure through PBL achieved higher cognitive learning outcomes and demonstrated stronger reasoning skills than those taught using conventional methods. Additionally, PBL helps students perceive chemistry learning as relevant and meaningful by connecting abstract concepts to everyday phenomena, thereby increasing motivation and engagement (Sofiyanita & Sari, 2024).

Despite the growing body of Research on e-LKPD and PBL in chemistry education, important Research gaps remain. Many existing studies focus on the development of e-LKPD without explicitly integrating the complete syntax of the Problem-Based Learning model into the instructional design. Other studies examine the effectiveness of PBL in improving learning outcomes, but do not embed the model within an interactive digital worksheet specifically designed to support abstract chemistry concepts such as atomic structure. Furthermore, limited Research has comprehensively evaluated PBL-based interactive e-LKPD by simultaneously examining its content validity, construct validity, practicality as measured by student responses, and effectiveness in improving learning outcomes. As a result, there is still insufficient empirical evidence regarding how a fully integrated PBL-based interactive e-LKPD can function as a valid, practical, and effective learning medium in Indonesian senior high school chemistry classrooms.

This study seeks to address these gaps by developing an interactive e-LKPD that explicitly integrates the complete syntax of the Problem-Based Learning model into atomic structure learning. The novelty of this Research lies in the systematic alignment between atomic structure content, contextual problem scenarios, and PBL learning stages, supported by interactive multimedia features that facilitate visualization and active engagement. Unlike previous studies that focus on isolated aspects of development or effectiveness, this Research adopts a holistic evaluation approach by examining the validity of the developed e-LKPD in terms of content and construct, its practicality based on student responses and classroom implementation, and its effectiveness measured through learning gains using n-gain analysis.

Accordingly, this study addresses the following research questions: (1) To what extent is the developed Problem-Based Learning (PBL)-based interactive e-LKPD valid in terms of content and construct validity for teaching atomic structure material?, (2) To what extent is the developed PBL-based interactive e-LKPD practical to be implemented in senior high school classroom learning based on students' responses and learning implementation?, and (3) To what extent is the developed PBL-based interactive e-LKPD effective in improving students' learning outcomes on atomic structure material as indicated by learning gains (n-gain)?. Therefore, the objective of this study is to develop and evaluate a

https://doi.org/10.51276/edu.v7i1.1382

PBL-based interactive e-LKPD for atomic structure material by (1) examining its content and construct validity, (2) analyzing its practicality based on students' responses and classroom implementation, and (3) measuring its effectiveness in enhancing senior high school students' learning outcomes through pre-test and post-test gain analysis (n-gain). Through this contribution, the study is expected to enrich the literature on digital learning media in chemistry education and to provide practical guidance for teachers in implementing meaningful, student-centered learning approaches that address the challenges of abstract-concept instruction in the era of globalization.

B. Method

The Research method used in this study is Research and Development (R&D). This study was conducted on 23 tenth-grade students from SMAN 1 Sambit in Ponorogo Regency. Data collection techniques included pre- and post-test scores and a student response questionnaire. The instruments used were the interactive e-LKPD itself, a student response questionnaire, and pre- and post-test questions. Quantitative test data were analyzed using the N-Gain Score to determine the effectiveness of the e-LKPD. Qualitative data from expert validation and student responses were analyzed descriptively.

The study followed the Lee and Owens development model, which was chosen for its comprehensive, systematic flow from analysis to evaluation. This model is particularly well-suited for developing interactive media as it includes stages for detailed evaluation and revision. The following sections are structured according to the phases of this model:

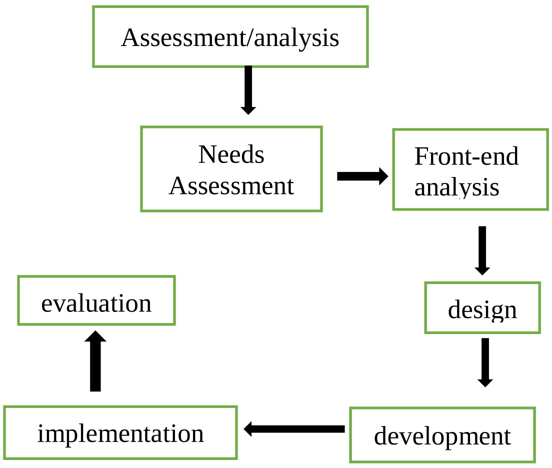

Figure 1. Lee and Owens Development Model
Source : (Lee & Owens, 2004)

The analysis stage consists of characteristic analysis, objective analysis, and material analysis. Characteristic analysis aims to obtain data related to motivation, prior knowledge, abilities, student learning experiences, and student learning style preferences. An objective analysis is conducted to determine the basic requirements for developing learning tools.

https://doi.org/10.51276/edu.v7i1.1382

Material analysis is carried out by referring to the curriculum implemented at SMAN 1 Sambit.

The design stage was carried out through several sequential steps, including determining the media specifications, organizing the material structure, and preparing the flowchart and storyboard as the main framework for developing the e-LKPD. The storyboard illustrates the overall structure of the e-LKPD, consisting of a cover page, a learning objectives section, and five activity sections that are systematically aligned with the syntax of the Problem-Based Learning (PBL) model. Based on the prepared flowchart and storyboard, the development stage focused on producing the e-LKPD in an interactive digital format that can be accessed flexibly via smartphones or laptops/computers, with atomic structure content enriched by interactive images and videos to support students' understanding. Furthermore, the implementation stage served as a concrete step to apply the developed e-LKPD in real classroom learning and to collect data regarding its quality, where the product was tested on 23 students of class X-2 at SMAN 1 Sambit. During this trial, students' pre-test and post-test scores were collected to evaluate the effectiveness of the interactive PBL-based e-LKPD in improving learning outcomes on atomic structure material.

The evaluation phase involved both formative and summative evaluations. Formative evaluation included analysis of feedback from expert validators, while summative evaluation analyzed student responses to the product. Formative evaluation consists of analyzing assessments and input from expert validators of media and materials, as well as teacher assessments. At this stage, a validity test is carried out and analyzed using the mode (Lutfi, 2021), and the test is declared valid if it receives a minimum score of 3.

After the product is deemed feasible based on the formative evaluation, the next step is the summative evaluation, which involves analyzing student responses to the e-LKPD product developed by the development team. Effectiveness was determined using the N-Gain Score, with a high category ($g \geq 0.7$) or a medium category ($0.3 \leq g < 0.7$) indicating that the e-LKPD is effective. The e-LKPD is deemed effective if each student has an N-Gain score of $0.7 < g < 0.3$ in the medium category or $g \geq 0.7$ in the high category (Hake, 1998).

C. Result

The first stage in this development Research was the analysis stage, which consisted of characteristic analysis, objective analysis, and material analysis. In the characteristic analysis, the researchers identified students' initial conditions, including learning motivation, prior knowledge, learning experiences, ability levels, and preferred learning styles as a basis for determining the most suitable learning media design. Furthermore, the objective analysis was conducted to formulate the basic requirements and learning targets that should be achieved through the development of an interactive e-LKPD, ensuring that the product aligns with the expected learning outcomes and supports student-centered learning activities. Meanwhile, the material analysis was carried out by referring to the curriculum implemented at SMAN 1 Sambit Ponorogo, which applies the Independent

https://doi.org/10.51276/edu.v7i1.1382

Curriculum, where atomic structure material is taught in Phase E. Based on classroom conditions and preliminary observations, it was found that the learning of atomic structure in chemistry classes at the school still rarely provides structured and varied practice questions that can train students' understanding and improve their learning outcomes. As a result, students may experience limitations in strengthening conceptual mastery and developing problem-solving skills on atomic structure, which reinforces the need for interactive learning resources that facilitate active engagement, provide meaningful exercises, and help students learn abstract concepts more effectively.

The second stage in this development Research was the learning media design stage, which focused on preparing a structured framework for the interactive e-LKPD before the product was fully developed. At this stage, the researchers determined the media specifications and arranged the atomic structure material systematically, followed by designing a flowchart to map the learning process and creating a storyboard as a detailed guide for the e-LKPD layout and learning activities. The storyboard was developed to ensure that each component of the e-LKPD supports student-centered learning and aligns directly with the syntax of the Problem-Based Learning (PBL) model, starting from the cover page and learning objectives section up to five activity stages that guide students through problem orientation, investigation, solution development, and evaluation. Therefore, the storyboard of the interactive e-LKPD developed in this study is presented in Table 1.

Table 1. Storyboard e-LKPD

e-LKPD design	e-LKPD Atomic Structure	Pages
Cover Page	Contains the title "E-LKPD ATOMIC STRUCTURE", student identity column, and teacher/student handle.	Page 1
Syntax 1 PBL: Orienting students to problems	The first syntax displays several examples of images related to atomic structure, such as a watermelon and atomic beans, for identification. Practice questions to express problems from the phenomena presented (Fluency Aspect).	Page 2
Syntax 2 PBL: Organizing students to learn	The second syntax includes descriptions to help students conduct investigations and learning videos on atomic structure.	Page 3
Syntax 3 PBL: Assisting independent and group investigations	The third syntax contains questions regarding: atomic number, atomic particle composition, isotopes, isotones, and isobars, to determine student abilities	Page 4-10
Syntax 4 PBL: Developing and presenting work results	The fourth syntax contains the results of observations or work on the questions provided in the presentation	
Syntax 5 PBL: Analyzing and evaluating the problem-solving process	The fifth syntax contains practice questions regarding the atomic structure material that has been studied	Page 11

The third stage in this study was the development stage, in which an interactive e-LKPD was produced based on the flowchart and storyboard designed in the previous phase. The researchers converted the planned learning sequence and PBL activities into a complete digital worksheet that can be used directly by students. The e-LKPD was designed in an

https://doi.org/10.51276/edu.v7i1.1382

interactive format and can be accessed through smartphones and laptops/computers, allowing flexible learning both inside and outside the classroom. It focuses on atomic structure material and is supported by multimedia features, including interactive images, embedded videos, and hyperlinks to strengthen students' understanding of abstract concepts. The final product consists of a cover page, learning objectives section, and activity pages structured according to the PBL syntax from Phase 1 to Phase 5. In addition, evaluation questions were provided to measure students' learning outcomes after completing the learning activities.

Figure 2. Parts of E-LKPD (a) Cover Page, (b) CP and ATP, (c) Hyperlink, (d) Phase 1, (e) Phase 2, (f) Phase 3, (g) Phase 4 and 5, (h) Evaluation Question

https://doi.org/10.51276/edu.v7i1.1382

After the e-LKPD has been developed, it must be validated by 2 lecturers and 1 chemistry teacher. Validation is conducted to ensure that the e-LKPD meets the eligibility standards for materials, media, and pedagogy. The following is a recapitulation of the results of the content validation and construct validity of the interactive e-LKPD:

Table 2. Results of Validation of e-LKPD Content for Each Aspect

No.	Aspects	Mode
1.	Suitability of e-LKPD content with learning achievements and learning objectives	4
2.	Suitability of e-LKPD content with learning model phases and written clearly	3
3.	Suitability of e-LKPD content with learning materials	3
4.	Suitability of the syntax content of the material in e-LKPD with learning objectives	3

Assessment data were analyzed using the mode, with validity determined if a minimum score of 3 was obtained. If validator scores differed, the median was used, and validity was confirmed if the score reached at least 3. Based on validation results from the validators, the e-LKPD developed received a mode value of 3 and was classified as valid.

Table 3. e-LKPD Construct Validation Results for each aspect

No.	Aspects	Mode
1.	Presentation includes images, videos, and hyperlinks used in e-LKPD that are clearly visible	3
2.	Language includes words or terms that are appropriate and consistent	3
3.	Graphics include a combination of writing and images in e-LKPD sequentially and systematically	3

Based on the validation results obtained from the validators, the developed e-LKPD received a mode value of 3 with a valid category.

The fourth stage is implementation; at this stage, the pre-test and post-test scores of students were obtained and analyzed quantitatively using the N-Gain Score calculation. The following are the results:

Table 4. Student Response Questionnaire Results Data

No.	Statement	Percentage
1.	Is e-LKPD media a fun medium to use in learning atomic structure?	100%
2.	Is e-LKPD media boring to use for learning atomic structure?	100%
3.	Do the instructions in e-LKPD for using the media make you want to learn the live-worksheet-based e-LKPD media?	86,96%
4.	Are you not interested in participating in learning using interactive e-LKPD media?	100%
5.	Do you recommend that your teacher use interactive e-LKPD media to help you learn?	86,96%
6.	Do you want other learning materials using interactive e-LKPD media?	91,30%
7.	Do you not want to use other learning materials with interactive e-LKPD?	78,26%
8.	Does the atomic structure material presented in interactive e-LKPD media	100%

https://doi.org/10.51276/edu.v7i1.1382

No.	Statement	Percentage
	not interest you in learning?	
9.	Does the interactive e-LKPD media help you understand the atomic structure material?	100%
10.	Do you still find the material on atomic structure difficult, even with the interactive e-LKPD media?	95,65%

Based on the questionnaire results, the score was 94.10%. Each question on the student response questionnaire had a result> 61%, indicating it was practical.

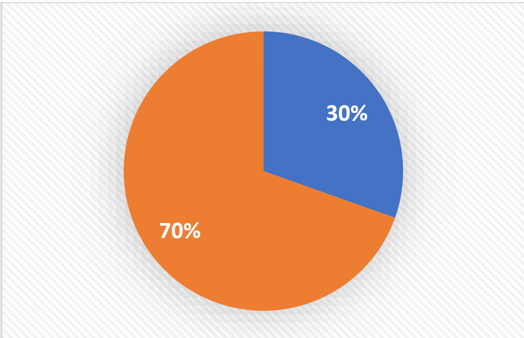

Figure 3. Cognitive Pre-test and Post-test Result Data

Based on the figure above, 16 students had an n-gain score ≥ 0.7 in the high category, and 7 students had an n-gain score of 0.3 ≥ g ≤ 0.7 in the medium category.

D. Discussion

The validity of the developed e-LKPD comprises two types: content validity and construct validity. Content validity was examined through the conformity of the e-LKPD with learning achievements and learning objectives, the suitability of the learning materials, and the alignment of the instructional syntax with the Problem-Based Learning (PBL) model. The e-LKPD was assessed as being in accordance with learning achievements and objectives, as evidenced by a mode score of 4 in the first aspect. In addition, the material's alignment with the learning objectives was rated as valid, with a mode score of 3, confirming the alignment between the e-LKPD content and the intended learning objectives. The learning materials and practice questions included in the e-LKPD were also aligned with the learning achievements of Phase E chemistry and the atomic structure sub-material, as indicated by a mode score of 3. These findings are consistent with the study by Febriningtyas & Dwiningsih (2024), which found that the suitability of e-LKPD to learning achievements and objectives contributes to more effective learning.

The second aspect of content validity showed suitability with the PBL learning model, achieving a mode score of 3. This result indicates that the e-LKPD was systematically organized according to the Problem-Based Learning framework, enabling students to engage in structured learning activities that emphasize problem orientation, investigation, and reflection. This finding supports the results reported by Utami et al (2025), who stated

https://doi.org/10.51276/edu.v7i1.1382

that e-LKPD developed in accordance with the PBL phases promotes more structured learning and helps students achieve deeper conceptual understanding.

Construct validity consisted of three aspects, namely presentation, language, and graphics. In terms of presentation, the e-LKPD obtained a mode score of 3 (valid), indicating that the content was clearly presented and easily accessible to students. The hyperlinks embedded in the e-LKPD functioned properly, including links to Google Forms and YouTube learning resources that supported independent learning and content exploration. Regarding language use, the e-LKPD also achieved a mode score of 3 (valid), as the language was simple, clear, and consistent with grammatical rules. Appropriate and consistent terminology was used to facilitate students' understanding of atomic structure concepts. In the graphic aspect, the e-LKPD obtained a mode score of 3 (valid), emphasizing readable typography, appropriate font sizes, and well-organized layouts. The use of appropriate frames and visual arrangements resulted in a neat, user-friendly appearance. These findings align with Research by Suradi et al (2024), which found that well-presented, visually valid e-LKPDs can positively Influence student learning outcomes.

After the validation stage, a limited field trial was conducted to evaluate the practicality and effectiveness of the developed e-LKPD. Data were collected through student response questionnaires, observations of student learning activities, and pre-test–post-test results on atomic structure material. The practicality indicators, based on both student responses and observational data, showed that all items achieved scores of at least 61%, indicating that the e-LKPD is practical to very practical. The overall practicality score reached 94.10%, indicating that the e-LKPD was perceived as very practical by students. This finding is consistent with the study by Mariza & Aini (2025), which emphasized that practical and user-friendly e-LKPD tools enhance learning efficiency and student engagement.

In terms of effectiveness, the pre-test and post-test results demonstrated significant improvements in students' learning outcomes, particularly in the cognitive domain. The increase in n-gain scores indicates that the interactive e-LKPD effectively supported the achievement of learning objectives related to atomic structure concepts. This improvement can be attributed to the integration of PBL principles with interactive digital features, which encouraged active engagement, problem-solving, and conceptual exploration. These results align with constructivist learning theory, proposed by Piaget and Vygotsky, which emphasizes that knowledge is constructed through active involvement and meaningful interaction with learning experiences. In addition, these findings are consistent with Research conducted by Vanzal & Dwiningsih (2023), which found that appropriate, well-designed learning media can significantly improve student learning outcomes.

Despite the positive results, this study also highlights the need for further investigation into the long-term impact of interactive e-LKPD on chemistry learning. Future studies should examine whether the observed learning gains are sustained over longer periods, such as across semesters or during cumulative assessments. Comparative studies involving students who use conventional learning media or alternative digital platforms

https://doi.org/10.51276/edu.v7i1.1382

could provide additional insights into knowledge retention and the transfer of learning to more advanced chemistry topics.

Moreover, although the implementation of the e-LKPD was effective in this study, its application in broader classroom contexts may face several challenges. These include stable internet access, variations in students' digital literacy, and limited teacher experience with digital learning platforms. Providing structured teacher training and adequate technical support may facilitate wider adoption and more effective integration of e-LKPD in school settings.

In addition, several learner-related factors may Influence learning outcomes when using e-LKPD, such as students' learning styles, prior knowledge, and access to personal devices or internet connectivity. Recognizing and addressing these factors is essential for optimizing the implementation of interactive digital learning media and ensuring equity in digital learning environments. By acknowledging these contextual and pedagogical considerations, the development and use of interactive e-LKPD can become more adaptive, inclusive, and impactful in diverse Indonesian high school learning contexts.

E. Implication

The findings of this study suggest that integrating Problem-Based Learning into interactive e-LKPD can be an effective instructional strategy for teaching abstract chemistry concepts, particularly atomic structure. For classroom practice, the developed e-LKPD provides teachers with a practical digital learning medium that supports active, student-centered learning and facilitates the visualization of abstract concepts through multimedia features. This approach is especially relevant for implementing the Independent Curriculum, which emphasizes meaningful learning and problem-solving skills. From a pedagogical perspective, the results reinforce the importance of combining instructional models with digital media design to enhance student engagement and learning outcomes. Additionally, the study suggests that interactive e-LKPDs can be adapted for other chemistry topics with similar abstract characteristics. For future development, these findings may inform educators, curriculum developers, and instructional designers in creating technology-based learning resources that align with 21st-century learning demands and support the development of higher-order thinking skills.

F. Limitation and Suggestion for Further Research

This study has several limitations that should be acknowledged. First, the Research focused solely on atomic structure, which may limit the applicability of the findings to other chemistry topics. Second, the participant sample was relatively small and drawn from a specific educational context, potentially affecting the generalizability of results. Third, the study duration was brief, making it difficult to assess long-term knowledge retention. Additionally, the interactive elements in the e-LKPD were not tailored to different learning styles, which could affect their effectiveness for diverse learners.

https://doi.org/10.51276/edu.v7i1.1382

Several directions are recommended for future Research. Expanding the scope to include other challenging chemistry concepts would test the broader applicability of interactive e-LKPDs. Studies should incorporate larger, more diverse samples across multiple institutions to enhance generalizability. Longitudinal Research designs would provide valuable insights into knowledge retention over time. Furthermore, developing adaptive versions of e-LKPDs that respond to individual learning preferences could maximise their educational impact. Comparative studies examining different digital learning tools would also help identify the most effective approaches for chemistry education.

G. Conclusion

This study developed and evaluated a Problem-Based Learning (PBL) based interactive electronic student worksheet (e-LKPD) for atomic structure material. The results indicate that the developed e-LKPD meets the criteria of validity, practicality, and effectiveness. Expert validation confirmed that the content, instructional design, language, and visual presentation were aligned with learning objectives and the PBL framework. Student responses and classroom implementation data demonstrated that the e-LKPD was practical and well-received, supporting active engagement during learning activities. Effectiveness analysis showed meaningful improvements in students' learning outcomes, as reflected by moderate to high n-gain scores. These findings suggest that integrating PBL into interactive digital worksheets can enhance students' conceptual understanding of abstract chemistry topics. Overall, the PBL-based interactive e-LKPD serves as a valid, practical, and effective learning medium for senior high school chemistry instruction and offers potential for broader application in technology-supported science learning.

References

Afrianis, N., & Ningsih, L. (2022). Analisis Kesulitan Belajar Siswa pada Materi Struktur Atom. *Konfigurasi: Jurnal Pendidikan Kimia dan Terapan,* *6*(2), 102. https://doi.org/10.24014/konfigurasi.v6i2.18617

Almarzuqi, A. A. A., & Mat, H. (2024). The Effectiveness of Blended Learning on STEM Achievement of Secondary School Students. *International Journal of Academic Research in Business and Social Sciences,* *14*(1), 1645–1661. https://doi.org/10.6007/IJARBSS/v14-i1/20140

Apriani, F., Syahrul, & Arafah, K. (2024). Analisis Kualitas Layanan Pembelajaran Kimia dalam Implementasi Kurikulum Merdeka di SMAN 2 Makassar. *Dalton: Jurnal Pendidikan Kimia dan Ilmu Kimia,* *7*(3), 172–181. https://doi.org/10.31602/dl.v7i3.15928

Ayob, H. H., Daleure, G., Solovieva, N., Minhas, W., & White, T. (2023). The Effectiveness of Using Blended Learning Teaching and Learning Strategy to Develop Students'

https://doi.org/10.51276/edu.v7i1.1382

Performance in Higher Education. *Journal of Applied Research in Higher Education, 15*(3), 650–662. https://doi.org/10.1108/JARHE-09-2020-0288

Ayunda, N., Lufri, & Alberida, H. (2023). Pengaruh Model Pembelajaran Problem Based Learning (PBL) Berbantuan LKPD Terhadap Kemampuan Berpikir Kritis Peserta Didik. *Journal on Education, 5*(2), 5000–5015. https://doi.org/10.31004/joe.v5i2.1232

Cahyana, U., Supatmi, S., Erdawati, & Rahmawati, Y. (2019). The Influence of Web-Based Learning and Learning Independence Toward Student's Scientific Literacy in Chemistry Course. *International Journal of Instruction, 12*(4), 655–668. https://doi.org/10.29333/iji.2019.12442a

Febriningtyas, S. A., & Dwiningsih, K. (2024). Validity of Problem Based Learning Oriented E-LAPD to Improve Chemical Literacy Skills of High School Students. *Jurnal Paedagogy, 11*(4), 797–806. https://doi.org/10.33394/jp.v11i4.12193

Hake, R. R. (1998). Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics, 66*(1), 64–74. https://doi.org/10.1119/1.18809

Hergenhahn, B. R., & Olson, M. H. (2008). *Theories of Learning* (6th ed.). Kencana Prenada Media Group.

Juniarni, D. I., Fadhilah, R., & Kurniawan, R. A. (2019). Pengembangan Permainan Lego Kimia Sebagai Media Pembelajaran Sub Materi Konfigurasi Elektron pada Siswa Kelas X SMA Muhammadiyah 1 Pontianak. *AR-RAZI Jurnal Ilmiah, 7*(1), 47–55. https://doi.org/10.29406/ar-r.v7i1.1381

Lathifah, M. F., Hidayati, B. N., & Zulandri. (2021). Efektifitas LKPD Elektronik Sebagai Media Pembelajaran pada Masa Pandemi Covid-19 untuk Guru di YPI Bidayatul Hidayah Ampenan Miqro'. *Jurnal Pengabdian Magister Pendidikan IPA, 3*(2), 25–30. https://doi.org/10.29303/jpmpi.v3i2.668

Lee, W. W., & Owens, D. L. (2004). *Multimedia-Based Instructional Design: Knowledge is the Key*. Pfeiffer.

Lestari, T., & Yerimadesi. (2024). Validitas dan Praktikalitas E-Modul Interaktif Berbasis Guided Discovery Learning pada Materi Sistem Periodik Unsur untuk Fase E SMA. *SCIENCE: Jurnal Inovasi Pendidikan Matematika dan IPA, 4*(4), 420–430.

Lutfi, A. (2021). *Research and Development (R&D): Implikasi dalam Pendidikan Kimia*. Jurusan Kimia FMIPA Universitas Negeri Surabaya.

Mampate, E. D. (2020). *Identifikasi Pemahaman Siswa pada Materi Struktur Atom di Kelas X Menggunakan Three-Tier Multiple Choice di SMA Negeri 1 Darul Imarah* [Skripsi]. Universitas Islam Negeri Ar-Raniry.

Mariza, F., & Aini, S. (2025). Validitas dan Praktikalitas E-LKPD Berbasis Problem-Based Learning Materi Momentum dan Impuls. *JIIP (Jurnal Ilmiah Ilmu Pendidikan), 8*(3), 2813–2818.

Mawarni, I. (2018). Deskripsi Kesalahan Siswa SMAN 3 Pontianak dalam Menyelesaikan Soal Struktur Atom dan Sistem Periodik Unsur. *Jurnal Pendidikan dan Pembelajaran, 7*(1), 1–10. https://doi.org/10.26418/jppk.v7i1.23512

Melliana, W., & Diana, L. M. (2024). Development of Multimedia Learning Android on Basic Network Engineering Orientation Material for Computer and Telecommunication Vocational Schools. *Edunesia: Jurnal Ilmiah Pendidikan, 5*(3), 1314–1329. https://doi.org/10.51276/edu.v5i3.917

Mufida, L., Subandowo, M. S., & Gunawan, W. (2022). Pengembangan E-Modul Kimia pada Materi Struktur Atom untuk Meningkatkan Hasil Belajar. *JIPI (Jurnal Ilmiah Penelitian dan Pembelajaran Informatika), 7*(1), 138–146. https://doi.org/10.29100/jipi.v7i1.2498

Nirmalasari, Y. (2020). The Correlation of Students' Interest in Character and Their Achievement on the Atomic Structure Topic. *JCER (Journal of Chemistry Education Research), 4*(2), 77–82. https://doi.org/10.26740/jcer.v4n2.p77-82

Nurmasita, Enawaty, E., Lestari, I., Hairida, & Erlina. (2023). Pengembangan E-LKPD Berbasis Problem-Based Learning (PBL) pada Materi Reaksi Redoks. *Jambura Journal of Educational Chemistry, 5*(1), 11–20. https://doi.org/10.34312/jjec.v5i1.15991

Prasetyo, F., & Novita, D. (2023). Improving Critical Thinking Skills With E-LKPD Oriented Think Pair Share for Chemical Equilibrium Material. *Hydrogen: Jurnal Kependidikan Kimia, 11*(4), 379–390. https://doi.org/10.33394/hjkk.v11i4.8156

Rachmawati, V., & Sukarmin, S. (2022). Pengembangan Multimedia Interaktif pada Pembelajaran Kimia Materi Struktur Atom Kelas X MIPA. *Chemistry Education Practice, 5*(2), 119–126. https://doi.org/10.29303/cep.v5i2.3557

Rocke, A. J., & Usselman, M. C. (2020). Chemistry. In *Encyclopaedia Britannica*. https://www.britannica.com/science/chemistry

Saleh, A., Oktarani, H., & Sari, R. A. I. (2022). Pengembangan Game Edukasi Kimia pada Materi Struktur Atom. *Jurnal Tadris Kimia IAIN Syekh Nurjati Cirebon, 1*(2), 12–21.

Sari, F. R., Anom, & Suhery, T. (2024). Pengaruh LKPD Berbasis Problem Based Learning Terhadap Hasil Belajar Siswa pada Materi Struktur Atom Kelas X SMA. *Jurnal Penelitian Pendidikan Kimia: Kajian Hasil Penelitian Pendidikan Kimia, 11*(1), 45–55.

Sofiyanita, & Sari, E. K. (2024). The Effect of The Problem-Based Learning (PBL) Model on Student Self-Efficacy in Basic Chemical Laws. *International Conference on Emerging …*, 176–184. https://icetse.uin-suska.ac.id/index.php/icetse/article/view/29

https://doi.org/10.51276/edu.v7i1.1382

Suradi, S., Prastowo, S. B., & Sutomo, M. (2024). Development of PBL-Based Interactive LKPD to Improve Elementary Students' Critical Thinking Skills in Science Learning. *Jurnal Paedagogy, 11*(2), 300. https://doi.org/10.33394/jp.v11i2.10034

Utami, R., Naswir, M., & Syahri, W. (2025). Development of E-LKPD Based on Integrated PBL STEM Material on Electrolyte and Non-Electrolyte Solutions Oriented to Critical Thinking Skills of High School Students. *Journal on Education, 7*(2), 12723–12730.

Vanzal, T., & Dwiningsih, K. (2023). Effectiveness of Android-Based Mobile Learning (M-Learning) on Molecular Shape Sub-Materials to Improve Students' Visual-Spatial Intelligence. *Jurnal Penelitian Pendidikan IPA, 9*(9), 7474–7483. https://doi.org/10.29303/jppipa.v9i9.4738

Yuliana, V., Copriady, J., & Erna, M. (2023). Pengembangan E-Modul Kimia Interaktif Berbasis Pendekatan Saintifik Menggunakan Liveworksheets pada Materi Laju Reaksi. *Jurnal Inovasi Pendidikan Kimia, 17*(1), 1–12. https://doi.org/10.15294/jipk.v17i1.32932

Author's Biography

	**Muhammad Husein Ashari.** Was born in Jombang City on March 4, 2002. Currently an undergraduate student in the Chemistry Education program at Surabaya State University (UNESA). Email: muhammadhusein.21047@mhs.unesa.ac.id
	**Dr. Sukarmin, M.Pd.** Was born in Magetan City on November 9, 1967. A lecturer at Surabaya State University (UNESA). Earned a Bachelor's degree in Chemistry Education from IKIP in 1992, a Master's degree in Science Education from IKIP in 1998, and a Doctoral degree in Chemistry Education from Surabaya State University (UNESA) in 2019. Email: sukarmin@unesa.ac.id