

Development and Validation of a PBL-ESD-Based E-Student Worksheet for Chemical Equilibrium in Solutions

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Abstract: The need to improve critical thinking and scientific argumentation skills in chemistry highlights the importance of integrating Education for Sustainable Development (ESD) and Problem-Based Learning (PBL) into teaching materials. In the context of chemistry, ESD encourages students to relate chemical concepts to real-life environmental, social, and economic issues, while PBL encourages inquiry through real-world problem scenarios. This study aims to develop a digital student worksheet (E-LKM) that innovatively combines the ESD approach and the PBL learning model for the topic of chemical equilibrium in solution. Unlike conventional worksheets, this E-LKM presents sustainability-based dilemmas—such as pollution from industrial waste and its effects on equilibrium systems—designed to trigger discussion, collaboration, and higher-order thinking. This study used the Research and Development (R&D) method, using the Thiagarajan 4D model, involving 40 students and 5 chemistry education lecturers from Riau Province as samples. Data analysis included validation by experts and user feedback on the practicality and readability of the results. E-LKM obtained a validation score of 115 (very good), a practicality score of 71, and a readability score of 60.767—both of which were classified as very good. These results indicate that E-LKM is a valid and practical tool for supporting chemistry learning, with a focus on sustainability, critical thinking, and scientific argumentation.

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INTRODUCTION

The rapid development of science and technology in the 21st century is a challenge for the world of education, especially higher education (Setiawan & Lenawati, 2020). 21st-century education combines knowledge and technology as well as real-life experiences in the learning process (Mazidah et al., 2020). The learning process carried out must be able to support the learning achievements of graduates or the achievement of the required competencies (Normawati et al., 2022). However, in reality, the learning process in higher education still does not effectively facilitate the development of 21st-century skills. Alhayat et al. (2022) in this research, it is explained that the 21st-century skills possessed by students, especially chemistry education students, are still relatively low. The low 21st-century skills possessed by students are due to the lack of variety in learning models used in learning.

Chemistry is a branch of science that not only studies facts, concepts, and basic principles, but also trains scientific process skills and forms critical and responsible attitudes. These skills include observation, measurement, classification, hypothesis formulation, experimentation, and drawing conclusions. Meanwhile, the attitude aspect in chemistry learning includes concern for the environment, curiosity, honesty, perseverance, discipline, accuracy, work safety, and the ability to work together (Abdullah et al., 2024). Thus, chemistry learning has great potential in forming students who not only understand concepts but also have an awareness of real issues faced by society.

However, the reality in the field shows that students' conceptual understanding of abstract topics in chemistry, such as chemical equilibrium, is still relatively low. To overcome this, a learning model is needed that can effectively link these concepts to real-life contexts. One approach that has proven effective is Problem-Based Learning (PBL), which can improve conceptual understanding, develop critical thinking skills, collaboration skills, and student learning motivation (Hmelo-Silver & Eberbach, 2012;

Wulandari & Shofiyah, 2018). In the context of chemistry learning, PBL provides space for students to investigate contextual problems as a basis for building a more meaningful scientific understanding.

On the other hand, global challenges such as environmental pollution, energy crises, and socio-economic inequality require learning that is not only based on science but also oriented towards sustainability. Education for Sustainable Development (ESD) is present as an educational approach that emphasizes the importance of awareness of environmental, social, and economic issues. ESD aims to form a young generation that cares about sustainability, can make wise decisions, and is responsible for the future (Burmeister et al., 2012).

The integration of ESD in the PBL model provides strategic opportunities in chemistry learning. By presenting contextual issues in the form of dilemmas related to chemistry topics, students are encouraged to think critically, solve problems collaboratively, and understand the social and environmental impacts of chemical phenomena. Therefore, the development of learning tools, such as electronic student worksheets (E-LKM) based on PBL and ESD, is an important step in creating a meaningful, contextual, and relevant learning experience that addresses the challenges of the 21st-century.

One of the topics in chemistry that has great potential to be linked to environmental issues is chemical equilibrium in solution, which encompasses acid-base reactions, buffer solutions, hydrolysis, and solubility equilibrium (K_{sp}). This topic is directly related to environmental phenomena, such as carbon dioxide (CO_2) emissions from human activities that dissolve in seawater and form carbonic acid, resulting in a decrease in sea pH. This phenomenon shows a real connection between chemical concepts and sustainability issues (Alloway, 2012). Therefore, combining this content with the PBL approach and ESD principles is an innovative opportunity in chemistry learning.

Students, especially prospective teachers, need to understand the urgency of environmental awareness and the importance of a responsible attitude towards environmental sustainability. According to Tan et al. (2014) and Chen (2020), understanding of environmental awareness must be developed not only from the aspect of knowledge, but also from the aspects of attitude and values. However, preliminary studies show that the learning process in higher education has not fully facilitated the development of an attitude of environmental responsibility. This is reinforced by Erna et al. (2023) who stated that there are still limited learning programs in Indonesian universities that support the development of students' environmental awareness.

In responding to these challenges, designing contextual teaching materials is a strategic solution. Teaching materials that are relevant to real life can improve scientific literacy, student activeness, and 21st-century skills (Ameliawati et al., 2021; Fikria & Prodjosantoso, 2021). One of the media that can be utilized is student worksheets (LKM). By utilizing technology, electronic LKM (E-LKM) is considered more efficient and flexible in supporting the learning process (Aldresti et al., 2021). Based on the interview results, it was known that chemistry learning in higher education still makes minimal use of electronic-based teaching materials, especially those that explicitly integrate PBL and ESD.

Based on this background, this study aims to develop a valid and practical PBL-ESD-based Chemical E-LKM in Solution. This E-LKM was designed to present dilemma problems that require students to link sustainability issues with chemical knowledge and involve critical thinking processes and collaborative discussions.

METHOD

This research was designed using a research and development (R&D) approach based on the 4-D model. This model was developed by Thiagarajan et al. (1974), which consists of 4 main stages: Define, Design, Develop, and Disseminate, as illustrated in Figure 1. The basis for choosing this 4D model was that each step of the development procedure was explained in detail, outlining what researchers will do when developing products in the form of teaching materials, books, or other educational materials. This model was chosen because it aimed to produce products in the form of E-LKM based on PBL-ESD.



Figure 1. Diagram of 4-D Models

This research was conducted in the Chemistry Education Study Program at the University of Riau and the Sultan Syarif Kasim State Islamic University of Riau, spanning the research period from December 2024 to January 2025. The subjects in this study were lecturers and students of chemistry education at the University of Riau. The readability test was conducted on 70 chemistry education students who had studied the material on chemical equilibrium in solutions. The practicality test was conducted on 5 chemistry education lecturers at the University of Riau and the Sultan Syarif Kasim State Islamic University.

In the product validation test, a validation sheet instrument was used to obtain assessments and responses from validators regarding E-LKM. According to Sugiyono (2016), product validation can be done by inviting several experts or experienced specialists to assess the newly designed product. Meanwhile, design validation is a process activity to assess a particular product made by a researcher. In this study, the product being assessed was the E-LKM Chemical Equilibrium in Solution. The Practicality Test was an assessment of an electronic LKM based on PBL-ESD on chemical equilibrium material in solution by chemistry education lecturers. Meanwhile, the readability test is conducted on students in a limited-scale trial. The readability test was performed to determine the level of readability of the electronic LKM developed.

Product validity was assessed using a validation sheet covering six aspects: content, construction, language, graphics, presentation, and operational aspects. Validation was conducted by five expert lecturers selected based on the following criteria: having >5 years of experience teaching chemistry, having developed learning media, and understanding the ESD approach. Each item on the validation sheet was scored on a Likert scale of 1–5, and the results were analyzed quantitatively. The practicality instrument consisted of 15 statements developed from pedagogical and technical aspects (ease of use, content relevance, ease of navigation, etc.). Meanwhile, readability was measured using a 14-item instrument that covered the clarity of instructions, language, and relevance to learners' experiences. All instruments underwent limited trials and were revised based on initial feedback to ensure clarity and relevance.

Validity, practicality, and readability analysis were assessed based on established aspects. The validity analysis of the E-LKM product of chemical equilibrium in solution was evaluated in terms of content/learning, construction, language, graphics, presentation, and operational. The practicality and readability analysis of this product were assessed in terms of content/learning, presentation, graphics, operational, and language.

The analysis technique involved calculating the percentage of the assessment. The data used in this study, namely the expert review score, was calculated on average to determine its validity. The validation sheet utilized an attitude measurement scale with a score of 1-5, represented by a Likert scale (√). Alternative positive attitude statements were converted into scores using a five-choice Likert scale to obtain quantitative data, as in Table 1.

Table 1. The Likert Scale table used in research instruments.

Information	Score
Very good	5
Good	4
Pretty good	3
Not enough	2
Very less	1

The data obtained from the assessment of feasibility by expert lecturers, practicality by chemistry education lecturers, and readability by students were analyzed descriptively quantitatively. Based on the assessment data obtained, it will be converted into an average score and categorized based on Table 2. The description of quantitative results into qualitative ones was done per aspect.

Table 2. Qualitative criteria for questionnaire results (Azwar, 2012)

Quantitative score range	Qualitative criteria
$X > Mi + 1.8 SBi$	Very good
$Mi + 0.6 SBi < X \leq Mi + 1.8 SBi$	Good
$Mi - 0.6 SBi < X \leq Mi + 0.6 SBi$	Pretty good
$Mi - 1.8 SBi < X \leq Mi - 0.6 SBi$	Not enough
$X \leq Mi - 1.8 SBi$	Very less

RESULT

E-LKM Products

The E-LKM that was created has undergone the recommended learning principles, starting with learning analysis, curriculum analysis, and culminating in the development of teaching materials. This teaching material was created in electronic form as an independent learning concept for students, because, in essence, students must have the ability to work independently and be more responsible for their actions.

E-LKM material on chemical equilibrium in solution is divided into 3 sub-learning. In each sub-learning, students will be given problems related to ESD issues. In its application, several issues were integrated into this learning, as follows:

- Learning activity 1 integrates the issue of acid rain with the sub-material on acid-base concepts and theories.
- Learning activity 2 integrates the issue of using indicators in industrial waste management with sub-materials on indicators and acid-base reactions.
- Learning activity 3 integrates the issue of increasing CO₂ levels and its impact on marine buffer systems with sub-topics on hydrolysis, buffers, and K_{sp}.

In this E-LKM, there was a space to identify problems, design hypotheses, and a space for group discussion and opinion exchange to improve students' critical thinking, argumentation, collaboration, and communication skills. The module was closed with an analysis and conclusion regarding the truth of the hypothesis designed by the students.

Product Validity

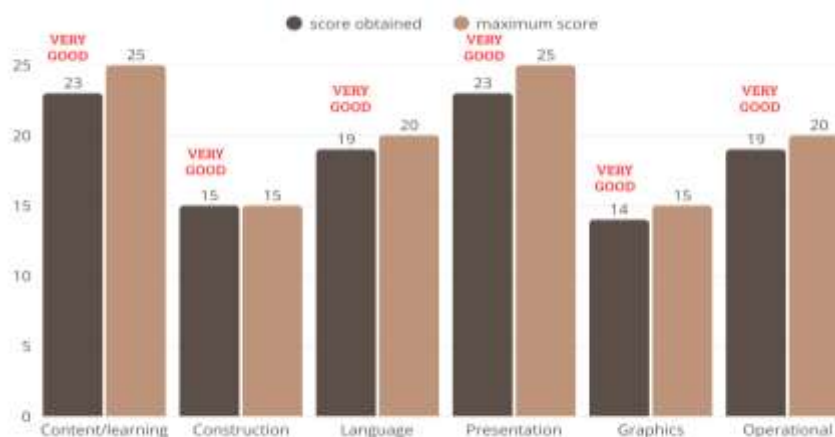


Figure 2. Product Validation Results

Based on the research conducted by the researcher, the validation results of all aspects of eligibility received a score of "Very Good". Based on these results, it can be concluded that the media developed by the researcher meets the very valid requirements. The results of the media eligibility validation were presented in Figure 2.

Product Practicality and Readability

A practical product can be identified by its ease of implementation for both students and educators, as well as its capacity to provide more comprehensive and enriched content compared to conventional textbooks. This practicality and readability test was conducted to assess whether the E-LKM Chemical Equilibrium product in this solution was practical from the user's perspective, specifically lecturers and students.

Based on the research conducted by the researcher, the practicality questionnaire was divided into several aspects: content/learning, presentation, graphics, operational, and language, with a total of 15 statements. The practicality test was conducted on 5 lecturers who taught the Basic Chemistry II course at the University of Riau and the Sultan Syarif Kasim State Islamic University of Riau. The results of this practicality test were presented in Figure 3, and it can be seen that the five aspects can be stated as "Very Good."

The Readability Test was conducted to determine students' responses regarding the use of the developed product. This Readability Test involved 40 chemistry education students with the criteria of having taken Basic Chemistry II. The readability questionnaire used consisted of 14 statements and yielded a result of 60.767, categorized as "Very Good."

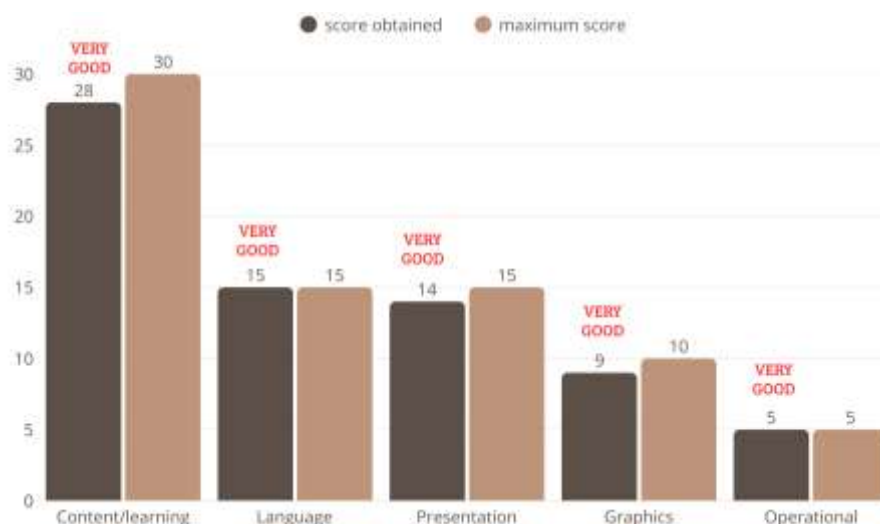


Figure 3. Product Practicality Test Results

DISCUSSION

This study resulted in the development of an electronic student worksheet (E-LKM) on the topic of chemical equilibrium in solution, designed using the 4D development model. The process included the stages of Define, Design, Develop, and Disseminate (not yet conducted). This product development was distinguished by its deliberate integration of Problem-Based Learning (PBL) and Education for Sustainable Development (ESD), resulting in a pedagogical tool that encourages active learning and critical engagement with sustainability issues.

The development of this E-LKM was designed not only to deliver chemical content conceptually but also to increase student engagement through contextual problem-based scenarios. This engagement was demonstrated through collaborative problem-solving activities, in which students were required to develop hypotheses, discuss solutions, and evaluate the sustainability implications of a chemical reaction. This strategy reflects a constructivist approach that facilitates deeper conceptual understanding through real-life connections.

The E-LKM aims to address common challenges in chemistry education—particularly the difficulty students experience in understanding abstract topics, such as equilibrium—by embedding real-world, sustainability-based dilemmas. Through carefully constructed problem scenarios, students were required to formulate hypotheses, collaborate in group discussions, and evaluate both scientific and social implications. For instance, integrating topics such as ocean acidification caused by CO₂ accumulation into buffer system discussions links chemical theory to environmental phenomena, thus fostering deeper conceptual understanding and systems thinking.

This E-LKM integrated ESD principles across three dimensions: environmental, social, and economic. The environmental dimension was addressed through issues such as acid rain, industrial waste pollution, and ocean acidification. The social dimension was represented by presenting dilemmas that require students to consider the social impact of industrial practices and chemical consumption. The economic dimension was explored by discussing the costs and benefits of sustainable approaches in waste treatment and emissions control. Each sustainability theme was tied to learning indicators and assessed through scientific argumentation rubrics and reflective questions measuring students' sustainability awareness.

Electronic LKM teaching materials based on PBL-ESD can be continued to the dissemination stage when a product has been declared feasible and practical. The feasibility of LKM can be seen from the results of expert validation, while the practicality of LKM can be seen from the results of practicality and readability tests (Abdullah et al., 2024). In line with the opinion Rahmawati et al. (2023) and Widiyani & Pramudiani (2021) which stated that validation testing was an effort to produce good and relevant teaching materials based on theoretical development foundations, and to ensure that the teaching materials were suitable for use in the learning process.

Validation of the E-LKM product of chemical equilibrium in this solution consisted of 6 aspects, namely, content, construction, language, graphics, presentation, and operational aspects. Based on the data analysis techniques presented by Azwar (2012), the results of the validation assessment were obtained from the six aspects (Figure 2), namely: content aspect (23); construction (15); language (19); graphics (23); presentation (14); and operational (19), with a total validation of all aspects of 115. The electronic LKM was reported to be very good based on the validation results of the six aspects.

The content aspect was declared very good, meaning that the content in the E-LKM was in accordance with the analysis of the material applicable to the Basic Chemistry II curriculum. In addition to that, CPL, CPMK, and learning objectives were aligned with the applicable curriculum. According to Weng et al. (2019), the accuracy of the material and content of the teaching materials with the curriculum used will make it easier for students to learn. The validity of the content in this LKM also showed the truth of the substance in it, so that it can avoid misconceptions and misunderstandings of concepts (Aprilia & Suryadarma, 2020; Buchori & Rahmawati, 2017). The construction aspect was stated as valid, which means that the LKM possessed characteristics that contained clear learning indicators and objectives and had been adjusted to the indicators developed. Imansari & Sunaryantiningsih (2017) stated that the clarity of learning indicators will make it easier for students to learn.

The linguistic aspect was related to the use of clear sentences that do not cause confusion (Ningsih & Mahyuddin, 2021). In the validity test of this E-LKM, this aspect received a very good category, indicating that the E-LKM already uses good and correct language that is easy to understand for students, thereby minimizing the occurrence of confusion when reading and using the E-LKM. The use of good and correct Indonesian will make it easier for students in learning (Afriyanti et al., 2021). The graphic aspect of this E-LKM also obtained a very good category. This means that the design and appearance of the E-LKM chemical equilibrium in this solution were good and attractive. This aspect concerned the use of font types and sizes, layout, the relationship between the images used, the material, and the giving of color to the E-LKM (Astra et al., 2020). Lestari & Parmiti (2020) also stated that this graphic aspect is essential because it can increase attention, motivation, and interest in learning.

The presentation aspect had a very good category, which means that this E-LKM has a concept and systematics that are appropriate. This E-LKM also has instructions for use and learning instructions that are easy for users to understand. The last aspect that showed the validity of this product was the operational aspect. In this E-LKM, the operational aspect was in a very good category, which means that

E-LKM provided a good response to users and makes it easy to find information within it. These two aspects will help users in operating and using E-LKM in learning (Istiyadi et al., 2022).

A development product is considered practical if it is easy for students or educators to use and provides more comprehensive content than textbooks. To test the practicality of a product, there were two stages, namely the practicality test and the readability test. The practicality test aims to evaluate the extent to which a product, instrument, or material is easy to apply and use in real conditions. The readability test aims to assess the extent to which the material (such as books, articles, test instruments, or applications) is easy to understand by the target audience. This was reinforced by Ibrahim & Subali (2017), who noted that the practicality of a development product can be assessed by observing whether book users experience difficulties in using it. To assess practicality, a practicality test was conducted among lecturers, and a readability test was administered to students.

The practicality test consisted of 5 aspects with a total of 15 statements. Aspects and statements include the suitability of the material, the suitability of CPMK, sub-CPMK, and learning indicators, ease of use, practicality, language, and attractiveness. The results of this practicality test received a positive response from all aspects, as shown in Figure 3, with a total of 71. This was in line with the research conducted Abdullah et al. (2024) namely, a positive teacher/lecturer response test can indicate that the product developed is effective in helping students in the learning process. The results of this practicality test were also in line with the validation results by experts, so it can be concluded that the E-LKM developed is very good.

Beyond technical validity, the practicality of the E-LKM was confirmed through two empirical measures: a lecturer-based practicality test and a student-based readability test. Lecturers noted that the E-LKM was easy to use and aligned well with learning indicators and outcomes. This indicated that the tool can be seamlessly integrated into classroom activities without requiring extensive adaptation. Students reported that the materials were not only easy to follow but also visually engaging and supportive of their learning. Importantly, the embedded videos and problem scenarios were considered relevant and helpful for building understanding.

A key contribution of this E-LKM was its ability to bridge the conceptual learning of chemistry with sustainability issues, a critical need in modern science education. For example, the inclusion of CO₂ emissions and their role in ocean acidification serves as a starting point for discussing equilibrium reactions, reflecting a deliberate effort to embed ESD principles. This shifted the narrative of chemistry learning from isolated concepts to socially and environmentally relevant problem-solving. As a result, students were encouraged to think critically about the impact of chemical phenomena on ecosystems and society, fostering both scientific and ethical reasoning.

The implementation of PBL-ESD through this E-LKM not only enhanced students' conceptual understanding but also nurtured 21st-century competencies such as collaboration, systems thinking, and sustainability literacy. In practice, this E-LKM can be used during small-group problem-solving sessions where students analyze contextual dilemmas, develop hypotheses, and communicate solutions—thus aligning pedagogy with real-world complexities.

Although the dissemination phase has not yet been carried out, the strong results from the validation and practicality stages suggest that the E-LKM has substantial potential for wider application. In future implementations, this tool could serve as a model for integrating sustainability into other abstract chemistry topics or across other STEM disciplines.

In conclusion, the results indicated that the PBL-ESD-based E-LKM was not only valid and practical but also pedagogically transformative. It provides chemistry educators with a scalable and meaningful instructional tool that supports active learning, contextual reasoning, and sustainability awareness—key pillars of education in the 21st-century.

These findings underscore the dual benefit of the PBL-ESD framework: improving scientific understanding while cultivating environmentally responsible mindsets. Moreover, the E-LKM offers a replicable model for integrating sustainability themes into other complex chemistry topics, thereby bridging the gap between theoretical learning and societal relevance. Its use in teacher education also supports pre-service chemistry teachers in designing learning environments that reflect 21st-century challenges.

CONCLUSION

The developed E-LKM has obtained very good feasibility in every aspect of the assessment by the validator. This E-LKM used an integrated PBL learning model ESD on the material Chemical Equilibrium in Solution, which was divided into three meeting topics. The results of the study showed that the feasibility, practicality, and readability of the product were classified as very good, with a total feasibility value of 115 out of 120, practicality with a value of 71 out of 75, and readability with a value of 60.767 out of 70. The developed product can help students understand the abstract concept of chemical equilibrium in solution. This E-LKM can be used for chemistry learning to measure its effectiveness on the desired variables.

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REFERENCES

- Abdullah, Herdini, & Putri, T. S. (2024). Validity and Practicality of E-Module Based on Phenomenon Based Learning Using Articulate Storyline on Material Colligative Properties of Solutions. *Jurnal Penelitian Pendidikan IPA*, 10(2), 764–775. <https://doi.org/10.29303/jppipa.v10i2.5837>
- Afriyanti, M., Suyatna, A., & Viyanti. (2021). Design of e-modules to stimulate HOTS on static fluid materials with the STEM approach. *Journal of Physics: Conference Series*, 1788(1). <https://doi.org/10.1088/1742-6596/1788/1/012032>
- Aldresti, F., Erviyenni, & Haryati, S. (2021). Pengembangan Lembar Kegiatan Mahasiswa Elektronik (e-LKM) berbasis Collaborative Learning Untuk Mata Kuliah Dasar-Dasar Pendidikan MIPA. *PENDIPA Journal of Science Education*, 5(3).
- Alhayat, A., Masriani, M., Rasmawan, R., Hairida, H., & Erlina, E. (2022). Profil Kemampuan Mahasiswa Pendidikan Kimia dalam Menyelesaikan Masalah Kontekstual Kimia. *Edukatif: Jurnal Ilmu Pendidikan*, 4(3), 3998–4009. <https://doi.org/10.31004/edukatif.v4i3.2743>
- Alloway, B. J. (2012). Heavy metals in soils. In *Springer* (Third edit). Springer. [https://doi.org/10.1016/s0165-9936\(96\)90032-1](https://doi.org/10.1016/s0165-9936(96)90032-1)
- Ameliawati, M., Permadi, A., & Maspupah, M. (2021). Development of Student Worksheets Based on Socio-Scientific Issues (SSI) on Climate Change Materials for Junior High School Students. *Scientiae Educatia*, 10(1), 64. <https://doi.org/10.24235/sc.educatia.v10i1.8887>
- Aprilia, I., & Suryadarma, I. G. P. (2020). E-module of mangrove ecosystem (emme): development, validation and effectiveness in improving students' self-regulated. *Biosfer*, 13(1), 114–129. <https://doi.org/10.21009/biosferjpb.v13n1.114-129>
- Astra, I. M., Raihanati, R., & Mujayanah, N. (2020). Development of Electronic Module Using Creative Problem-Solving Model Equipped with HOTS Problems on The Kinetic Theory of Gases Material. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, 6(2), 181–194. <https://doi.org/10.21009/1.06205>
- Azwar, S. (2012). *Penyusunan skala psikologi* (2nd ed.). Pustaka Pelajar.
- Buchori, A., & Rahmawati, N. D. (2017). Pengembangan E-Modul Geometri dengan Pendekatan Matematika Realistik di Sekolah Dasar. *Jurnal Pendidikan Dasar*, 1(4), 23–29.
- Burmeister, M., Rauch, F., & Eilks, I. (2012). Education for Sustainable Development (ESD) and chemistry education. *Chemistry Education Research and Practice*, 13(2), 59–68. <https://doi.org/10.1039/c1rp90060a>
- Chen, J. (2020). Environmental Education, Knowledge and Awareness in China: A Case of Xiamen University Students. *ASIANetwork Exchange A Journal for Asian Studies in the Liberal Arts*, 27(1), 54–72. <https://doi.org/10.16995/ane.298>
- Erna, M., Alimin, M., Lee, H., Suryawati, E., Albeta, S. W., & Priyambada, G. (2023). Enhancing Indonesian college students' views of social responsibility of scientists and engineers: The enact model intervention. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(3). <https://doi.org/10.29333/ejmste/13000>

- Fikria, U. R. A., & Prodjosantoso, A. K. (2021). Teaching Tools Based on Socio-Scientific Issues on Acid-Base Topic for Chemistry Learning at High School: A Needs Analysis. *Proceedings of the 6th International Seminar on Science Education (ISSE 2020)*, 547(Isse 2020), 289–295. <https://doi.org/10.2991/assehr.k.210326.041>
- Hmelo-Silver, C. E., & Eberbach, C. (2012). Learning Theories and Problem-based Learning. In *Researching problem-based learning in clinical education: The next generation*. Springer. <https://doi.org/10.1007/978-94-007-2515-7>
- Ibrahim, & Subali. (2017). *Pengembangan Bahan Ajar & Pengembangan Instrumen Pengukuran Pembelajaran Biologi*. Workshop Pendidikan Biologi FKIP ULM.
- Imansari, N., & Sunaryantiningsih, I. (2017). Pengaruh Penggunaan E-Modul Interaktif Terhadap Hasil Belajar Mahasiswa pada Materi Kesehatan dan Keselamatan Kerja. *VOLT: Jurnal Ilmiah Pendidikan Teknik Elektro*, 2(1), 11. <https://doi.org/10.30870/volt.v2i1.1478>
- Istiyadi, M., Yulinda, R., Amalina, D., & Fahmi. (2022). Validity and Practicality of Articulate Storyline Learning Media on Environmental Pollution Materials for Junior High School Students. *Jurnal Penelitian Pendidikan IPA*, 8(6), 2599–2604. <https://doi.org/10.29303/jppipa.v8i6.1639>
- Lestari, H. D., & Parmiti, D. P. (2020). Pengembangan E-Modul IPA Bermuatan Tes Online untuk Meningkatkan Hasil Belajar. *Journal of Education Technology*, 4(1), 73–79.
- Mazidah, Erna, M., & Anwar, L. (2020). Developing an Interactive Chemistry E-Module for Salt Hydrolysis Material to Face the Covid-19 Pandemic. *Journal of Physics: Conference Series*, 1655(1). <https://doi.org/10.1088/1742-6596/1655/1/012051>
- Ningsih, S. Y., & Mahyuddin, N. (2021). Desain E-Module Tematik Berbasis Kesantunan Berbahasa Anak Usia Dini di Taman Kanak-Kanak. *Jurnal Obsesi: Jurnal Pendidikan Anak Usia Dini*, 6(1), 137–149. <https://doi.org/10.31004/obsesi.v6i1.1217>
- Normawati, E., Indana, S., & Purnomo, T. (2022). the Effectiveness of Socio-Scientific Issues-Based Electronic Student Worksheet To Improve Critical Thinking Skills for Class Vii Students. *Jurnal Penelitian Pendidikan IPA*, 7(2), 60–66. <https://doi.org/10.26740/jppipa.v7n2.p60-66>
- Rahmawati, Y., Akbar, M. J., Budi, S., & Ridwan, A. (2023). Exploring value-based learning environment for sustainable development in education: Integration of socio-scientific issues in chemistry learning. *3rd International Conference on Science, Mathematics, Environment, and Education: Flexibility in Research and Innovation on Science, Mathematics, Environment, and Education for Sustainable Development, ICoSMEE 2021*, 040006. <https://doi.org/10.1063/5.0106206>
- Setiawan, D., & Lenawati, M. (2020). Peran dan Strategi Perguruan Tinggi dalam Menghadapi Era Society 5.0. *RESEARCH: Computer, Information System & Technology Management*, 3(1), 1. <https://doi.org/10.25273/research.v3i1.4728>
- Sugiyono. (2016). *Statistika untuk Penelitian*. Alfabeta.
- Tan, H., Chen, S., Shi, Q., & Wang, L. (2014). Development of green campus in China. *Journal of Cleaner Production*, 64, 646–653. <https://doi.org/10.1016/j.jclepro.2013.10.019>
- Thiagarajan, S., Dorothy a', A., & Melvyn I. Somme! (1974). *Instructional development for training teachers of exceptional children: A sourcebook*. Indiana University. [https://doi.org/10.1016/0022-4405\(76\)90066-2](https://doi.org/10.1016/0022-4405(76)90066-2)
- Weng, F., Ho, H. J., Yang, R. J., & Weng, C. H. (2019). The influence of learning style on learning attitude with multimedia teaching materials. *Eurasia Journal of Mathematics, Science and Technology Education*, 15(1), 1–9. <https://doi.org/10.29333/ejmste/100389>
- Widiyanti, A., & Pramudiani, P. (2021). Pengembangan Lembar Kerja Peserta Didik (LKPD) Berbasis Software Liveworksheet pada Materi PPKn. *DWIJA CENDEKIA: Jurnal Riset Pedagogik*, 5(1), 132. <https://doi.org/10.20961/jdc.v5i1.53176>
- Wulandari, F. E., & Shofiyah, N. (2018). Problem-based learning: Effects on student's scientific reasoning skills in science. *Journal of Physics: Conference Series*, 1006(1). <https://doi.org/10.1088/1742-6596/1006/1/012029>