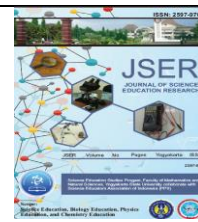




Journal of Science Education Research

Journal homepage: <https://journal.uny.ac.id/index.php/jser/index>

ISSN: 2597-9701



Development of E-LKM Inquiry Learning oriented STEM Respiration and Photosynthesis Materials to Improve Science Literacy and Student Investigation Ability

I. E. Agustina^{1*} , S. Aloysius² 

Department of Biology Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta

*Corresponding Author. Email: intanagustina29@gmail.com

Abstract

This study aims to produce E-LKM Inquiry learning media oriented STEM towards respiration and photosynthesis materials that are appropriate, practical, and effective in increasing science literacy and student investigation capabilities. This research is a study and development (R&D) with the Addie model. In this study, it was not only a trial in a small scale, but also a large scale test was conducted using the Non-Equivalent Control Group quasi-experimental design in 62 students divided into experimental and control groups. The instrument used was in the form of a scientific literacy test and a student investigation capability questionnaire. Data analysis was carried out using the Manova test. The results showed that the E-LKM Inquiry Learning is STEM-oriented and practical to support the learning process with a very good category, based on validation by media experts and materials and based on the assessment of educators and students. In addition, E-LKM Inquiry Learning oriented STEM also affects in increasing science literacy and students' investigation abilities simultaneously from GIS grades. Manova test of 0,000 (<0.05). In conclusion, the E-LKM Inquiry Learning oriented STEM is declared feasible, practical, and effectively used in learning, especially in respiration and photosynthesis material. This media is proven to be able to increase science literacy and students' investigation abilities simultaneously.

Keywords:

E-LKM, inquiry learning, STEM, Science Literacy, Investigation Ability

History


Received:
December
16, 2025

Revised:
March 10,
2026

Accepted:
April 24,
2026

How to cite:

Agusina, I.E., Aloysius, S. (2026). Development of E-LKM Inquiry Learning oriented STEM Respiration and Photosynthesis Materials to Improve Science Literacy and Student Investigation Ability. *Journal of Science Education Research*, 10(1), 156-164. <https://doi.org/10.21831/jser.v10i1.93281>.

This open access article is distributed under a (CC-BY SA 4.0 License) 

1. INTRODUCTION

In this era, information technology has become a foundation in human life. This gives consequences and concrete impacts on the field of education, where education must be adjusted to meet future needs through the use of technology. The era of the Industrial Revolution 4.0 brought significant changes, including in the Indonesian education system. Changes in the education system certainly have an impact on the role of the teacher. Teachers are required to be more efficient in producing students who are able to face the challenges of the industrial era. Therefore, the education system must also experience adjustments (Amir, 2018).

Industrial Revolution 4.0 also gave birth to the concept of education 4.0, which is marked by the use of digital technology in the teaching and learning process (Amir, 2018). In the field of education, the use of information technology has changed ways of learning, how to obtain information, and how to interpret information. In the midst of rapid technological advances, this change has a significant impact in educating and educating the nation's children. Information technology also encourages the emergence of various interesting and creative innovations, including the application of E-LKM Inquiry learning oriented STEM.

Inquiry learning learning model is a pedagogical approach that emphasizes the process of scientific investigation as the core of learning activities (Lestari et al., 2022). In this model, students are encouraged to actively explore problems, formulate hypotheses, design and conduct experiments, and analyze and conclude data based on the findings obtained. Through this series of stages, inquiry learning not only provides students with conceptual understanding, but also practice critical thinking skills, problem solving skills, and scientific attitudes (Townley, 2018). This relevant approach is applied in science learning because it invites students to experience the construction process of knowledge actively and reflectively, thus supporting learning that is more meaningful and contextual (Gómez & Suárez, 2020).

As a complement to the inquiry learning model, the STEM Learning Approach (Science, Technology, Engineering, and Mathematics) is integrated to strengthen the applicative and interdisciplinary dimensions in science learning (Çalık et al., 2013; Wannomai et al., 2024). The STEM approach aims to connect science concepts with the application of technology, engineering design, and mathematical skills in a whole unit. This approach is in line with the demands of 21st century education (Alan et al., 2021) emphasizes the importance of the development of science and technology literacy through the ability to observe, reason, innovate, and solve complex real problems (Lederman et al., 2019). Therefore, learning inquiry learning model is expected to strengthen the ability of science literacy and scientific investigations of students holistically and directed.

With the development of the times and the demands of the 21st century, education needs to be directly linked to science, technology, engineering, and mathematics. Therefore, it is very necessary to have a STEM-based teaching material so that education is not lagging behind. However, not all schools are able to apply it because of various obstacles, one of which is limited facilities. Mastery of science and technology (science and technology) is now an important key to facing future challenges, such as improving the quality of life, equitable development, and the development of human resources.

Science education plays an important role in preparing students who have science literacy, namely the ability to think creative, logical, and initiative in responding to community issues that arise due to the development of science and technology. Science education is expected to be a means for students to study themselves, the environment, and develop potentials that can be applied in daily life. By mastering science literacy, students are expected to be able to understand the environment and problems in modern society that are very dependent on the development of science and technology (Silvia, 2019).

Science literacy can also be an indicator of the quality of education and human resources of a country. The results of the 2003 PISA survey OECD, (2003) define science literacy as the ability to use science knowledge, identify questions, and draw conclusions based on evidence to understand and make decisions about nature and changes due to human activity. According to Bybee, (2009) Science literacy is the knowledge and understanding of the concepts and scientific processes needed for personal decision making, contributing to socio-cultural activities, and economic productivity. Meanwhile, Gormally et al (2012) states that science literacy is the ability of individuals to distinguish science facts from various information, understand and analyze scientific research methods, and organize and interpret quantitative data and science information.

Based on the preliminary study conducted by researchers through interviews, questionnaires, and questions at STKIP Al-Maksum, it is noted that teaching materials are not yet available in the form of E-LKM Inquiry Learning oriented in the practice of general biology learning in respiration and photosynthesis material. Initial data shows that the ability of student science literacy on the topic is still relatively low, which is 46.62%. The results of interviews with lecturers also revealed that the ability of student investigations is still low, especially since the Pandemic period. The results of the questionnaire for the need for teaching materials distributed to students, obtained data that 79.9% of students stated the need for E-LKM Inquiry Learning oriented STEM. Therefore, it is necessary to conduct research on "Development of ELKM Inquiry Learning oriented STEM Respiratory and Photosynthesis Materials to increase science literacy and student investigation capabilities".

2. RESEARCH METHOD

This research is a study and development (R&D) with the Addie model aims to produce certain products and test their level of effectiveness. The Addie model has a major focus on achieving learning objectives, including in designing and developing learning media which is a systematic model in the design of learning evaluation (Lee & Owens, 2004). This process is described more clearly in the **Figure 1**.

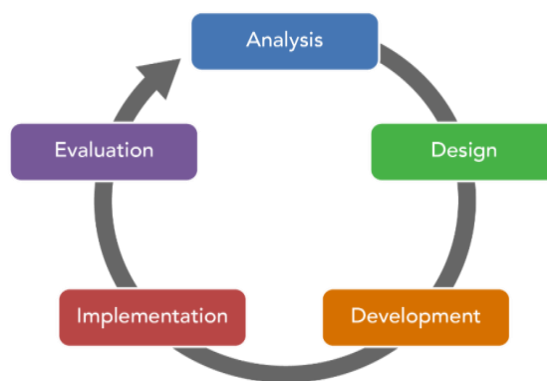


Figure 1. Addie Development Scheme

The product developed in the form of E-LKM Inquiry Learning is STEM-oriented by following the five main stages of Addie, namely: Analysis, Design, Development, Implementation, and Evaluation. 1) Analysis stage aims to gather important information related to the learning needs of lecturers and students, identify the characteristics of the products to be developed, and examine problems in the learning process. 2) The design stage is focused on the preparation of systematic, interactive, and contextual e-LKM structures and content according to the curriculum and characteristics of students. This process refers to media selection, format selection, and prototype development. 3) At the development stage, including making materials that integrate multimedia elements, learning activities, and test questions to support the understanding of science concepts, namely respiration and photosynthesis. 4) The implementation stage is carried out to test the effectiveness of the media developed. 5) The evaluation phase is carried out to examine input, analyze the quality and achievement of the objectives of the use of media after being implemented.

The trials in this study were conducted in small scale at the "Development" stage and a large scale at the "implementation" stage. The small scale trial involves the participation of media experts and material experts through filling out questionnaires to analyze the feasibility of the media, as well as educators to analyze the practicality of the media developed. Whereas in a large scale trial carried out by implementing E-LKM inquiry learning oriented STEM towards learning. Science literacy data and student investigation capabilities, obtained from pretest and posttest values. Research analysis uses a non-Equivalent Control Group quasi-experimental design in 62 students divided into experimental and control groups. The instrument used was in the form of a scientific literacy test and a student investigation capability questionnaire. Then a Manova test was carried out on data to see the effectiveness of E-LKM Inquiry Learning oriented towards Science Literacy and Student Investigation Ability. In addition, an effect size test is conducted which aims to measure the extent of the effectiveness of learning interventions using the Cohen's D formula:

$$d = \frac{(MA - MB)}{\sqrt{\frac{SDA^2 + SDB^2}{2}}}$$

Information:

- d* = Effect Size Value (big influence)
- M_A* = The average experimental class score
- M_B* = The average control class score
- SD_A* = The standard deviation of the experimental class
- SD_B* = The standard deviation of the control class

(Hake, 1998)

Criteria for the Interpretation of Effect Size Value Based on Cohen's presented in **Table 1.**

Table 1. Effect Size Criteria

Effect Size Value	Criteria
0,2	Small
0,5	Currently
0,8	Big

(Hake, 1998)

3. RESULT AND DISCUSSION

This study produced the main product in the form of E-LKM media based on STEM-oriented Inquiry Learning, which was developed to increase science literacy and student investigation capabilities. This media is presented in the form of digital applications as a means of independent learning, including E-LKM with learning content, experimentation, and contextual problem solving. The focus of the development topic is respiration and photosynthesis, using the Addie development model which consists of the analysis, design, development, implementation, and evaluation stages.

Analysis

The analysis phase includes an analysis of the needs of lecturers and students, analysis of student characteristics, task analysis, and material analysis. *First*, the results of the analysis of the needs of lecturers and students show that learning is still dominated by lecture methods and textbooks, with less integrating technology and explorative activities. Interviews with lecturers revealed the absence of STEM-based learning media, especially in respiration and photosynthesis material. In fact, technology infrastructure on campus is quite adequate, and students have access to digital devices. Therefore, the results of this analysis become an important basis for designing an E-LKM Inquiry Learning based on STEM. *Second*, the results of the preliminary study in the analysis of student characteristics, it is known that STKIP Al Maksum students have low-literacy and investigative literacy, especially in respiration and photosynthesis material. This is exacerbated by online learning and lack of interactive media. However, as many as 79.9% of students show high interest in STEM-based teaching materials to increase understanding and learning involvement.

Third, based on the results of task analysis in general biological lectures at STKIP Al Maksum Task is still theoretical and has not encouraged the scientific capabilities of students, such as experimental and data analysis. The absence of STEM-based media, especially E-LKM, as well as lack of use of digital technology is an obstacle in the development of scientific literacy and investigation skills. This finding is an important basis for designing STEM-based E-LKM which is more contextual and applicative. *Fourth*, the material analysis is done by identifying the main concepts that will be taught in respiration and photosynthesis material, which will later be published in the E-LKM Inquiry Learning media oriented STEM. This analysis is arranged systematically in accordance with the order of presentation and detailing relevant concepts.

Design

Media is designed in the form of digital applications that are compatible with Android and laptops, to support independent and collaborative learning. Which allows flexibility in learning anytime and anywhere, supporting material exploration independently and project -based. The media platform is chosen based on ease of access and characteristics of students. The selection of formats is prepared with the main menu: learning achievements, instructions, activities, evaluation, references, and profiles. Learning activities include theories and practicum with the theme of photosynthesis and respiration, presented in STEM-based E-LKM. There is also a pretest-posttest feature and the delivery of results via email. The following is an E-LKM Inquiry Learning oriented STEM design that can be seen in [Figure 2](#).



Figure 2. E-LKM Inquiry Learning STEM-oriented

Development

The development process is carried out through a series of stages that include validation and revision. A small scale test to analyze the feasibility of E-LKM media by media and material experts can be seen in [Table 2](#).

Table 2. Expert validation results

Expert	Aspect	Total Validation Score	Maximum score	Category
Materi	Learning	24	28	Very good
	Material content	14	16	Very good
Total		38	46	Very good
Media	Visual and Audio	31	36	Very good
	Software engineering	22	24	Very good
Total		53	60	Sangat Baik

Based on the validity data in Table 2. It is known that the E-LKM Inquiry Learning oriented STEM product is declared very feasible for learning. The results of the validation of the material expert include aspects of learning and total content score 38 out of 46 including the very good category, showing that the contents and structure of the material according to learning needs. While the results of the validation of media experts include visual-audio aspects and software engineering a total score of 53 out of 60 including the very good category. This indicates that the appearance, audio, and technical functionality of the media meet high quality standards to support effective and attractive learning. This is in line with previous findings which state that good media strongly supports the involvement and motivation in the learning process (Sukiyani, 2023). Professional visual appearance and clear audio quality can improve learning experiences and help students to be more focused in the material delivered, thus supporting the effectiveness of learning as a whole (Zhao, 2022).

Material aspects are assessed from the integration of learning content with a STEM approach, clarity of learning achievements, as well as the relevance of content to strengthening scientific literacy and investigation capabilities, with the results of the assessment which is also included in the very good category. Integration in the STEM approach is very crucial because it integrates science, technology, engineering, and mathematics in the applicative context. This approach invites students to understand the concepts holistically and apply them in real life (Benu et al., 2024). The clarity of learning achievements also clarify expectations at each stage of learning, so that students can achieve learning goals more directed and measurable (El Nagdi & Roehrig, 2020).

In addition, the relevance of E-LKM content to the strengthening of science literacy and investigative abilities is a strategic aspect in learning design. When learning materials are in line with the development of science literacy, students not only master scientific facts, but are also trained to think critically and investigate natural phenomena (Salam, 2023). Emphasis on research and problem solving in the context of STEM encourages students to develop the ability to face real challenges and respond to the needs of the community (Fajrina et al., 2023). The assessment results show that the ELKM Inquiry Learning oriented is not only functioning as a provider of information, but also as a means of developing the skills of the 21st century. This reflects the commitment of developers in designing learning media that not only meets academic standards, but also relevant to the dynamics and demands of the contemporary education world (Winarni & Koto, 2020). Furthermore, the results of practical analysis can be seen in [Table 3](#).

Tabel 3. The results of the media practicality assessment by educators (lecturers)

Expert	Aspect	Total Validation Score	Maximum score
Visual and Audio	33	36	Very Good
Software engineering	21	24	Very Good

Learning	25	28	Very Good
Materi or Content	15	16	Very Good

The results of the E-LKM practical assessment based on inquiry learning oriented STEM in **Table 3**. Shows the "very good" category in all aspects. Visual and audio aspects get a score of 33 of 36, signifying an attractive and comfortable appearance. Interesting visual aspects and audio are clearly very important, especially for complex material such as respiration and photosynthesis that are often abstract, so that it requires interesting and informative visualization to facilitate understanding. Research shows that learning media that have strong visual and audio elements can significantly increase the understanding of concepts by students (Salam, 2023). The software engineering aspect gets a score of 21 out of 24, which reflects that this media is responsive, easy to operate, and stable without significant technical problems. Success in creating reliable software is very important to maintain student focus and prevent frustration that often arises when facing non -intuitive technology. Research in the field of education shows that easily accessible technology can improve learning experiences and accelerate the learning process (Banks & Barlex, 2020).

Furthermore, the learning aspect obtained a score of 25 of 28, showing that E-LKM has supported an active and structured teaching strategy in accordance with the principle of STEM. Activities that prioritize exploration, problem solving, and integration cross -disciplined become the center of effective learning in the context of STEM (Salam, 2023). It is important to prepare students to face challenges in the real world, where cross -disciplinary competencies are needed. The last aspect, namely material or content, obtains a score of almost perfect of 15 out of 16, indicating that the substance of the material is in accordance with learning needs and is presented coherent, accurately, and relevant to the targeted learning achievements.

Implementation

At this stage a large scale trial is carried out by implementing the media developed in learning to test the effectiveness of using the Manova test. This is done to determine the effectiveness of the use of E-LKM Inquiry Learning media oriented stem towards science literacy and simultaneous student investigation capabilities. Manova was chosen because of its excellence in testing the average difference of two or more dependent variables simultaneously between groups, so that they are able to capture complex interactions that may occur between these variables in one model of analysis (Tabachnick & Fidell, 2011).

In the context of this study, E-LKM Inquiry Learning oriented STEM oriented is positioned as an independent variable that has a significant contribution to increasing science literacy and the ability to investigate students. Science literacy reflects the ability of students in understanding scientific concepts, applying them in the context of real life, and making decisions based on scientific evidence (Vieira & Mello, 2023). Meanwhile, the ability of scientific investigations refers to the ability to design, implement, and evaluate the process of systematic scientific investigations (Jumiarni et al., 2023). Both are important indicators in the 21st century learning, especially in the STEM Education Approach that emphasizes the integration of knowledge and skills across discipline to solve real problems. Test results MANOVA presented in **Table 4**.

Table 4. Test Results MANOVA Science Literacy and Student Investigation

<i>Multivariate Tests^a</i>				
	<i>Effect</i>	<i>Value</i>	F	<i>Sig</i>
Class	<i>Pillai's Trace</i>	.361	16.633 ^b	.000
	<i>Wilks' Lamda</i>	.639	16.633 ^b	.000
	<i>Hotteling's Trace</i>	.564	16.633 ^b	.000
	<i>Roy's Largest Root</i>	.564	16.633 ^b	.000

Test Results MANOVA in **Table 4**. shows that the significance value of 0,000 smaller than 0.05, alternative hypotheses are accepted, so there is a significant effect of STEM-oriented E-LKM Inquiry Learning on increased scientific literacy and student investigation capabilities. The significance value below the 0.05 threshold provides a strong statistical justification that this finding is not the result of random variability, but the real effect of the learning intervention applied. In this context, an integrated STEM-based learning approach in E-LKM is able to encourage students to develop high-level cognitive abilities through the combination of theories and practices in scenarios that are relevant to real life.

Furthermore, the results of the calculation of the Effect Size using Cohen standards further strengthened these findings. Effect Size of 1.15 for science literacy is included in the large category (large effect), which shows that the treatment is not only statistically significant, but also has a practical impact which is substantial in increasing student science literacy. Meanwhile, the Effect Size of 0.68 for investigative capabilities is in the

medium to high category, which shows that although the effect is not as big as in science literacy, interventions still contribute to meaningful contributions practically in improving these capabilities.

This is in line with the previous literature which states that the STEM -based learning model is able to develop science literacy, which is a conceptual understanding of scientific phenomena, as well as increasing student investigative abilities, including formulating hypotheses, designing experiments, interpreting data, and drawing conclusions (Salam, 2023). These findings make an important contribution to the development of technology-based learning practices that are integrated with the STEM approach, as well as strengthening the argument that instructional innovations such as E-LKM can be an effective solution in improving the quality of higher education, especially in strengthening science literacy competencies and student investigative abilities simultaneously.

The comprehensive interpretation of this result shows that E-LKM Inquiry Learning oriented STEM is able to be an effective learning instrument in developing student science skills. A stronger influence on science literacy can be explained by a learning approach that emphasizes conceptual understanding through the integration of science, technology, engineering, and mathematics content in the context of the real world. Meanwhile, an increase in investigation capabilities indicates that students not only understand concepts, but also begin to develop science process skills, such as observing, formulating hypotheses, and analyzing data.

E-LKM Inquiry Learning is STEM-oriented in increasing science literacy and investigative abilities students have important implications for the development of learning media in the modern education era. This effectiveness not only reflects the success of E-LKM as instructional tools, but also emphasizes the crucial role of learning media that is designed systematically and based on an integrative approach in improving the quality of the process and learning outcomes (Hutomo et al., 2022; Subali et al., 2023).

In the context of STEM education, learning media does not only function as a delivery of information, but as a facilitator which is able to integrate the concepts of science, technology, engineering, and mathematics in contextual and applicative learning experiences. ELKM Inquiry Learning is STEM-oriented designed with the approach to invite students to not only gain passive knowledge, but also actively involved in the process of exploration, problem solving, and scientific investigations. In other words, this media encourages meaningful learning (meaningful learning) based on constructivism and oriented to the development of 21st century skills (Mutaqqiin, 2023; Zahroh & Yuliani, 2021).

This finding also strengthens the urgency of the use of interactive digital media in high learning, especially in responding to the increasingly digitized challenges of education and demands cross -disciplinary skills. The effectiveness of E-LKM inquiry learning oriented STEM shows that learning media that integrate technology with appropriate pedagogical principles can accelerate the achievement of essential competencies such as science literacy, and investigation capabilities. This is in line with the shift in the educational paradigm from content -based teaching to holistic and sustainable learning capacity building (Andaresta & Rachmadiarti, 2021; Rambe et al., 2023).

In addition, the success of this media provides a strategic contribution in the planning and implementation of STEM-based curriculum, especially in designing learning experiences that are able to accommodate the needs of diverse students. Lecturers and educators can make ELKM as a model of development of learning media based on project, problem -based, or inquiry based on the changing times and the needs of the community (Marzuqi & Ahid, 2023; Nurmi et al., 2020; Wicaksana & Natalia, 2023; Yuniati & Nashikhah, 2023).

Evaluation

At the evaluation phase in the process of revision and final product development, a comprehensive assessment of the effectiveness and quality of ELKM media is based on the results of the trial and validator test. Evaluation includes a revision of various aspects, such as differences in learning steps between control classes and experiments, typical error corrections, MFI improvements, and improving task collection mechanisms on E-LKM media. This stage ensures that the final product is not only academically valid, but also practical and ready to be implemented in learning.

4. CONCLUSION

Development of E-LKM Inquiry Learning Media STEM-oriented in respiration and photosynthesis material produces products that are decent, practical, and effective. E-LKM inquiry learning oriented STEM is declared feasible to be used to increase science literacy and student investigation capabilities with a very good category, based on the validation of material and media aspects by experts. Whereas the E-LKM Inquiry Learning oriented STEM is declared practical used to support the learning process and improve science literacy and the ability of student investigations in the very good category, based on the assessment of educators (lecturers) and students. In addition, test results MANOVA shows that the significance value of 0,000 (<0.05)

indicates that alternative hypotheses are accepted, so that the use of STEM-oriented E-LKM Inquiry learning has proven effective in increasing both variables simultaneously.

REFERENCES

- Alan, B., Zengin, F. K., & Keçeci, G. (2021). Effects of science, technology, engineering, and mathematics education using Algodoo to prospective science teachers' scientific process and education orientation skills. *Journal of Education*, 203. <https://doi.org/10.1177/00220574211044542>
- Amir, H. (2018). *Metode pengembangan penelitian dan pengembangan R&D*. CV Literasi Nusantara Abadi. PT Bumi Aksara.
- Andaresta, N., & Rachmadiarti, F. (2021). Pengembangan e-book berbasis STEM pada materi ekosistem untuk melatih kemampuan literasi sains siswa. *Berkala Ilmiah Pendidikan Biologi (Bioedu)*, 10. <https://doi.org/10.26740/bioedu.v10n3.p635-646>
- Banks, F., & Barlex, D. (2020). Enabling the 'E' in STEM. In P. J. Williams & D. Barlex (Eds.). *Pedagogies in Design and Technology Education*. <https://doi.org/10.4324/9780429317736-7>
- Benu, M. Y. T., Parno, P., Handayanto, S. K., Yuliati, L., Putri, M. K., Jatmiko, B., & Ali, M. (2024). The effect of STEM approach with assessment formative in PBL on the problem-solving ability of prospective physics teacher on mechanical wave. *Proceedings of the International Conference on Science Education and Technology (ISET)*, 118–126. https://doi.org/10.2991/978-2-38476-275-0_10
- Bybee, R. W. (2009). Perspective for the U.S.: A presentation for the NCES PISA research conference. *National Center for Education Statistics*.
- Çalik, M., Turan, B., & Coll, R. K. (2013). A cross-age study of elementary student teachers' scientific habits of mind concerning socioscientific issues. *International Journal of Science and Mathematics Education*, 12. <https://doi.org/10.1007/s10763-013-9458-0>
- El Nagdi, M., & Roehrig, G. H. (2020). Gender equity in STEM education: The case of an Egyptian girls' school. *IntechOpen*. <https://doi.org/10.5772/intechopen.87170>
- Fajrina, S., Lufri, L., Ahda, Y., & Alberida, H. (2023). Validity of project learning model based on STEMS to improve creativity in the 21st century. *Proceedings of the 5th International Conference on Educational Development and Quality Assurance (ICED-QA 2023)*, 9–17. https://doi.org/10.2991/978-94-6463-166-1_3
- Gómez, R. L., & Suárez, A. M. (2020). Do inquiry-based teaching and school climate influence science achievement and critical thinking? Evidence from PISA 2015. *International Journal of STEM Education*, 7. <https://doi.org/10.1186/s40594-020-00240-5>
- Gormally, C., Brickman, P., & Lutz, M. (2012). Developing a Test of Scientific Literacy Skills (TOSLS): Measuring information evaluation and argumentation. *CBE—Life Sciences Education*, 11. <https://doi.org/10.1187/cbe.12-03-0026>
- 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. <https://doi.org/10.1119/1.18809>
- Hutomo, B. A., Saptono, S., & Subali, B. (2022). Development of e-module based on science, technology, engineering, and mathematics (STEM) to improve science literacy of junior high school students. *Journal of Innovative Science Education*, 11. <https://doi.org/10.15294/jise.v10i1.54066>
- Jumiarni, D., Yennita, Y., Irawati, S., Winarni, E. W., & Yanti, F. (2023). Development of biotechnology e-module based on integrated project based learning with STEM approach. *Proceedings of the 5th International Conference on Educational Technology and Online Learning*, 181–188. https://doi.org/10.2991/978-2-38476-108-1_17
- Lederman, J. S., Lederman, N. G., Bartels, S. L., Jiménez, J. P., Akubo, M., Aly, S., & Zhou, Q. (2019). An international collaborative investigation of beginning seventh grade students' understandings of scientific inquiry: Establishing a baseline. *Of Research in Science Teaching*, 56. <https://doi.org/10.1002/tea.21512>
- Lee, W. W., & Owens, D. L. (2004). Multimedia-based instructional design: Computer-based training, web-based training, distance broadcast training. *Jossey-Bass/Pfeiffer*, 5.
- Lestari, N. A., Hariyono, E., Dwikoranto, D., Prahani, B. K., & Deta, U. A. (2022). Project-based inquiry-science: An innovative learning for thinking, teaching and assessing science-physics. *Momentum: Physics Education Journal*, 6. <https://doi.org/10.21067/mpej.v6i1.6254>
- Marzuqi, B. M., & Ahid, N. (2023). Perkembangan kurikulum pendidikan di Indonesia: Prinsip dan faktor yang mempengaruhi. *JOIEM (Journal of Islamic Education Management)*, 4. <https://doi.org/10.30762/joiem.v4i2.1284>

- Mutaqqiin, A. (2023). Pendekatan STEM (Science, Technology, Engineering, Mathematics) pada pembelajaran IPA untuk melatih keterampilan abad 21. *Jurnal Pendidikan MIPA*, 13. <https://doi.org/10.37630/jpm.v13i1.819>
- Nurmi, N., Yunita, A., Yusri, R., & Delyana, H. (2020). Efektivitas penggunaan lembar kerja mahasiswa berbasis project-based learning (PjBL) terintegrasi ICT. *Aksioma: Jurnal Program Studi Pendidikan Matematika*, 9. <https://doi.org/10.24127/ajpm.v9i4.3190>
- OECD. (2003). *First results from PISA 2003*. Organisation for Economic Co-operation and Development.
- Rambe, A. H., Siregar, N., & Fitri, N. (2023). LKM berbasis kreativitas pada matkul media dan sumber belajar di MIS/SD Prodi Pendidikan Guru Madrasah Ibtidaiyah UINSU Medan. *Research and Development Journal of Education*, 9. <https://doi.org/10.30998/rdje.v9i2.20430>
- Salam, H. (2023). STEM education: Its effects on the quality of teachers and students in the 21st century. *Advances in Social Science, Education and Humanities Research*, 31–39. https://doi.org/10.2991/978-2-38476-020-6_4
- Silvia, A. (2019). *Pengembangan LKPD berbasis science, technology, engineering, and mathematics untuk menumbuhkan keterampilan literasi sains siswa kelas X MIA SMA Negeri 14 Medan T.P. 2019/2020*. SKRIPSI.
- Subali, B., Ellianawati, E., Faizah, Z., & Sidiq, M. (2023). Indonesian national assessment support: Can RE-STEM Android app improve students' scientific literacy skills? *International Journal of Evaluation and Research in Education (IJERE)*, 12. <https://doi.org/10.11591/ijere.v12i3.24794>
- Sukiyani, F. (2023). Investigating elementary school teachers' challenges and needs in implementing STEM education: The case of Nusa Tenggara Barat Indonesia. *AHSSEH* 9. https://doi.org/10.2991/978-94-6463-220-0_9
- Tabachnick, B. G., & Fidell, L. S. (2011). Multivariate analysis of variance (MANOVA). In M. Lovric (Ed.), *International Encyclopedia of Statistical Science*, 902–904. https://doi.org/10.1007/978-3-642-04898-2_394
- Townley, A. L. (2018). Teaching and learning science in the 21st century: Challenging critical assumptions in post-secondary science. *Education Sciences*, 8. <https://doi.org/10.3390/educsci8010012>
- Vieira, B. R., & Mello, W. (2023). Potenciais pedagógicos da relação entre a cultura maker e a educação STEM no ensino de biologia. *Atas de Educação*, 9–17. <https://doi.org/10.22533/at.ed.6102318122>
- Wannomai, M., Nuangchalerm, P., & Islami, R. A. Z. El. (2024). Stoichiometry understanding of upper secondary students through active science learning. *Journal of Education and Learning (EduLearn)*, 18. <https://doi.org/10.11591/edulearn.v18i4.20962>
- Wicaksana, E. J., & Natalia, D. (2023). Pengembangan E-LKM berbasis case method untuk meningkatkan keterampilan mahasiswa dalam menyusun instrumen evaluasi pembelajaran. *Jurnal Pendidikan MIPA*, 13. <https://doi.org/10.37630/jpm.v13i4.1128>
- Winarni, E. W., & Koto, I. (2020). Pengembangan lembar kegiatan mahasiswa (LKM) dengan model project-based learning (PjBL) untuk meningkatkan literasi sains pada perkuliahan <https://doi.org/10.33369/dikdas.v3i2.13875> IPA pendidikan dasar. *Jurnal Pembelajaran Dan Pengajaran Pendidikan Dasar*, 3. <https://doi.org/10.33369/dikdas.v3i2.13875>
- Yuniati, M., & Nashikhah, M. (2023). Lembar kerja mahasiswa berbasis project based learning pada mata kuliah busana anak. *Jurnal Ilmiah Pendidikan Dan Pembelajaran*, 7. <https://doi.org/10.23887/jipp.v7i3.57996>
- Zahroh, D. A., & Yuliani, Y. (2021). Pengembangan E-LKPD berbasis literasi sains untuk melatih keterampilan berpikir kritis peserta didik pada materi pertumbuhan dan perkembangan. *Berkala Ilmiah Pendidikan Biologi (Bioedu)*, 10. <https://doi.org/10.26740/bioedu.v10n3.p605-616>
- Zhao, Y. (2022). Systematic analysis of research trends in STEAM/STEM education based on big data. *Proceedings*, 155–168. https://doi.org/10.2991/978-94-6463-012-1_18