

Development of Scientific Conceptual Understanding by Model-based learning for Grade 11 Students

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ABSTRACT:

The most significant problem in science learning among students in rural areas of Thailand and countries in the Asian region is their low level of scientific conceptual understanding. This research is an action research study aimed at developing scientific conceptual understanding among students learning through Model-based learning for Grade 11 students. The target group consisted of 31 Grade 11 students at Yangtalatwittayakhan School, Yang Talat District, Kalasin Province, a secondary school in Thailand whose context closely reflects the aforementioned problem. The research instruments consisted of: 1) nine Model-based learning lesson plans on the topics of the circulatory system and lymphatic system, 2) a scientific conceptual understanding assessment, and 3) student interview forms. Data were analyzed using basic statistics, namely percentages. The research findings revealed that students showed development in scientific conceptual understanding, reaching either a complete understanding or a correct but incomplete understanding level. In action cycles 1, 2, and 3, the numbers of students achieving this level were 15, 23, and 31, representing 48.39%, 74.19%, and 100.00%, respectively. It can be seen that the number of students who developed scientific conceptual understanding increased after learning through Model-based learning. The key finding was that Model-based learning helps explain, predict, and discuss scientific phenomena and enables students to construct better scientific concepts, even for children in rural areas. Furthermore, the use of quality instructional media to support Model-based learning can contribute to the development of biology teaching and learning in secondary schools in rural areas of Thailand

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1. Introduction

Science is the foundation of economic, technological, health, and cultural advancement in modern society. Numerous research studies indicate that countries that prioritize science tend to achieve more stable growth and greater long-term competitiveness (Levytskyi et al., 2021; Pinto & Teixeira, 2020; Satpayeva et al., 2020). In teaching and learning, teachers must therefore emphasize helping students develop accurate scientific concepts, as concepts serve as systematic mental representations of the natural world and are central to scientific discourse encompassing visible phenomena, invisible phenomena, and various processes (Kampourakis, 2018). If students do not understand concepts or hold misconceptions, they will be unable to learn new concepts effectively. Particularly at the primary school level, understanding of scientific concepts directly influences scientific attitudes; that is, children with better conceptual understanding tend to have more positive scientific attitudes and higher achievement (Ghina Dhaniyah Salsabil et al., 2024; Sekaringtyas et al., 2024). Certain natural phenomena may not be directly observable or may be too complex to understand readily (Bryce et al., 2016).

Science learning at the primary and secondary levels is often filled with deeply embedded misconceptions arising from everyday life experiences and insufficiently deep instruction. If left uncorrected from the outset, these misconceptions continuously affect science learning at higher levels. Commonly found types of misconceptions in science include, for example, topics related to nature and the environment such as the water cycle, where misunderstandings about evaporation and condensation occur (Amelia Fariza et al., 2025). In biology content, misconceptions about the functioning of the human body and living organisms have also been documented (Department of Educational Training The Islamia University of Bahawalpur Pakistan et al., 2022; Hasnawati et al., 2022). This is consistent with research across the Asian region, which collectively indicates that scientific

misconceptions at the primary and lower secondary levels are considerably high and occur in very fundamental topics “ranging from force, light, and matter to heat”. Common problem areas and frequently misunderstood topics include, for instance, Indonesia and Malaysia, where high rates of misconceptions have been found in topics related to force and motion, such as the belief that only living things can exert force, as well as issues concerning light and vision (Kamilah et al., 2025; Utami et al., 2024).

Scientific misconceptions represent a major and recurring problem across the same fundamental topics. The key causes frequently identified regarding scientific conceptual problems include: prior conceptions and everyday life experiences that conflict with science; issues related to textbooks and instructional media that use difficult language, inappropriate analogies, or incomplete explanations, leading to permanent misconceptions (Dewi & Wulandari, 2021; Laeli et al., 2020); and, most critically, teaching methods that emphasize memorization without connecting to real-world situations, and that lack experimental activities and opportunities to challenge prior thinking (Kamilah et al., 2025). Given these problems and causes, and recognizing that certain natural phenomena cannot be directly observed or are too complex to comprehend (Bryce et al., 2016), models are necessary to help explain findings that scientists have obtained through experimental study.

Model-based instruction in science education is grounded in the important notion that children learn science through constructing, using, evaluating, and revising models of phenomena, rather than through memorizing content. This directly addresses the correction of misconceptions, because it makes the ideas in students' minds visible, testable, and modifiable. The key principles are: 1) models serve as mental representations of phenomena such as diagrams, cycles, charts, and 3D models used to explain, predict, and discuss scientific phenomena (Louca & Zacharia, 2012); 2) model-based learning views learning as a cycle of observing, gathering evidence, constructing models, comparing with real phenomena, and iteratively revising in order

to build deeper and more sophisticated understanding; and 3) a substantial body of research proposes that model construction is the true core of science learning and should be embedded in curricula at all levels (Carroll & Park, 2026; Gilbert & Justi, 2016).

In this research, the research team selected as the target group 31 Grade 11 students in the academic year 2021 at Yangtalatwittayakhan School, Yang Talat Sub-district, Yang Talat District, Kalasin Province, Thailand. The content selected for the study was from the biology subject on the topics of the circulatory system and lymphatic system content areas in which students demonstrated low levels of scientific conceptual understanding and were unable to answer questions or explain the underlying principles. Students held misconceptions across all concepts related to the content. This school is representative of the large number of secondary schools in Thailand that share a similar context to those found across the Asian region. An action research process was employed in order to provide foundational data for research aimed at addressing students' scientific misconceptions in rural areas, and to contribute to the ongoing development of teaching and learning practices.

2. Methodology

Research Objectives

To develop scientific conceptual understanding among students learning through Model-based learning for Grade 11 students.

Target Group: 31 students in Grade 11/2 at Yangtalatwittayakhan School, Yang Talat Sub-district, Yang Talat District, Kalasin Province, in the academic year 2021, selected through purposive sampling. All students held misconceptions across every concept related to the content. This school is representative of the large number of secondary schools in Thailand that share a similar context to those found across the Asian region. An action research process was employed to provide foundational data for research aimed at addressing scientific misconceptions among students in rural areas.

Research Content: Biology subject content for Grade 11, covering the topics of the circulatory system and lymphatic system, in accordance with the learning outcomes of the Science and Technology Learning Area (Revised Edition B.E. 2560), under the Basic Education Core Curriculum B.E. 2551.

Research Duration: This research was conducted during the second semester of the academic year 2021.

Research Instruments

1. Model-based learning lesson plans on the topics of the circulatory system and lymphatic system, consisting of 9 lesson plans with a total instructional time of 13 hours.

2. A scientific conceptual understanding assessment on the circulatory system and lymphatic system, designed as a Two-tier Multiple Choice Diagnostic Test. Tier 1 measures scientific conceptual understanding using four-choice multiple choice questions. Tier 2 requires students to provide reasoning for their selected answers, enabling detailed classification of students' levels of scientific conceptual understanding. The instrument demonstrated content validity, with an Index of Item-Objective Congruence (IOC) across the entire test ranging from 0.8 to 1.0.

3. A student interview form aimed at collecting data in three areas: opinions regarding teaching and learning methods; opinions regarding instructional media and activities used; opinions regarding time allocation in learning management; and opinions regarding problems and obstacles encountered during instruction. The instrument demonstrated content validity with an Index of Congruence (IOC) of 1.0.

Data Collection

This study employed Action Research, comprising 4 steps carried out across 3 action cycles. The data collection procedures were as follows:

Cycle 1: A survey of students' problem conditions was conducted and interviews with the classroom teacher revealed that students

experienced difficulties in scientific conceptual understanding. Learning theories were then studied to identify appropriate solutions, and the research team selected Model-based learning as the instructional approach. Lesson plans were subsequently developed. In Step 2 (Implementation), 3 lesson plans covering the topics of substance transport in animal bodies, the structure of the heart and blood vessels in humans, and the relationship between blood vessel size and blood flow velocity were implemented with the target group. Scientific conceptual understanding was assessed and students were interviewed following instruction. Upon reflection, it was found that students had difficulties comprehending the content and did not understand the scoring criteria prior to taking the assessment. These issues were used to inform the development of lesson plans for Cycle 2.

Cycle 2: Improvements were made by providing a detailed explanation of the scoring criteria for the scientific conceptual understanding assessment before students began the test. Lesson plans were also revised to include a content summary through questioning at the end of each lesson, in order to review students' knowledge and check their understanding before the assessment. Three revised lesson plans covering the topics of substance transport in the human body, measurement of cardiac function and blood pressure, the direction of blood flow in veins, and heart diseases and disorders were implemented with the target group. Scientific conceptual understanding was assessed and students were interviewed following instruction. Upon reflection, it was found that some students still held misconceptions about the core concepts of the phenomena studied, and that some students misread the test questions, resulting in incorrect answers. These issues were used to inform the development for Cycle 3.

Cycle 3: Lesson plans were further revised. During the lesson introduction phase, students were provided with video clips, and real-life situations were connected to the content being studied. Discussion topics were created to encourage knowledge exchange among students, and guidance was provided throughout the

learning process to monitor students' understanding. The assessment was also improved by making questions clearer where a question asks which option is incorrect or correct, the key word should be bolded or underlined for emphasis. Three revised lesson plans covering the topics of blood components, blood types and blood transfusion, and the lymphatic system were implemented with the target group. Scientific conceptual understanding was assessed and students were interviewed following instruction. Upon reflection, it was found that students demonstrated correct understanding of the phenomena studied, though some responses remained incomplete, as students provided correct answers and reasoning but were missing certain key elements of the phenomena under study. A further improvement was recommended: during the answer-checking and solution-explanation phase, the teacher should provide detailed clarification of both the correct answers and the reasoning behind each answer, in order to guide students in subsequent learning sessions.

Data Analysis

The levels of scientific conceptual understanding used to determine whether students had developed their scientific conceptual understanding were analyzed based on results from the assessment on the circulatory system and lymphatic system. The classification followed the framework of Westbrook and Marek, which consists of 5 levels: 1) Complete Understanding: CU, 2) Partial Understanding: PU, 3) Partial Understanding with Specific Alternative Conception: PS, 4) Alternative Conception: AC and 5) No Understanding: NU (Westbrook & Marek, 1991).

3. Results

The results of each cycle are presented as follows.

1. Results of Cycle 1 are presented in Table 1 below.

Table 1: Levels of Scientific Conceptual Understanding in Cycle 1

Students (n = 31)	CU and PU Level	PS and AC Level
Number of students	15	16
Percentage	48.39	51.61

As shown in Table 1, in Cycle 1, there were 15 students whose scientific conceptual understanding scores reached the correct but incomplete understanding or complete understanding level (CU and PU), representing 48.39% of the total number of students. There were 16 students whose scores fell below the correct but incomplete understanding or complete understanding level (PS and AC), representing 51.61% of the total. This indicates that more than half of the students had not yet reached the correct but incomplete or complete understanding level. The research team then analyzed students' response patterns from the assessment and identified the problem that students were unable to provide correct reasoning. Furthermore, some students selected correct answers but wrote explanations reflecting misconceptions or incorrect understanding of the phenomena studied. These issues led to the revision of lesson plans for Cycle 2.

2. Levels of Scientific Conceptual Understanding in Cycle 2

Table 2: Students meeting and not meeting the criteria in Cycle 2

Students (n = 31)	CU and PU Level	PS and AC Level
Number of students	23	8
Percentage	74.19	25.81

As shown in Table 2, there were 23 students whose scores reached the correct but incomplete understanding or complete understanding level (CU and PU), representing 74.19% of the total.

There were 8 students whose scores fell below that level (PS and AC), representing 25.81% of the total. The research team then analyzed the response patterns of students across all four understanding levels Complete Understanding (CU), Partial Understanding (PU), Partial Understanding with Specific Alternative Conception (PS), and Alternative Conception (AC) and identified the problem that some students still held misconceptions about the phenomena studied, were able to select only the correct answer but could not provide written reasoning for their choice, or provided reasoning that deviated from the phenomena studied. These issues led to further revision of lesson plans for Cycle 3.

3. Levels of Scientific Conceptual Understanding in Cycle 1 in Table 3 below.

Table 3: Students meeting and not meeting the criteria in Cycle 3

Students (n = 31)	CU and PU Level	PS and AC Level
Number of students	31	0
Percentage	100.00	0.00

As shown in Table 3, all 31 students reached the correct but incomplete understanding or complete understanding level, representing 100.00% of the total, with no students falling below this level

4. Discussion

This research aimed to develop scientific conceptual understanding through Model-based learning in the biology subject, covering the topics of the circulatory system and lymphatic system, for Grade 11 students. The findings revealed that all 31 students in the target group reached either the Complete Understanding (CU) or Partial Understanding (PU) level. When examined by action cycle, the results were as follows.

Cycle 1: A total of 15 out of 31 students, representing 48.39%, reached the Complete

Understanding (CU) or Partial Understanding (PU) level. This is attributed to the fact that Model-based learning is a process through which students come to understand and explain various phenomena by continuously constructing and revising models of those phenomena, which helps students better visualize abstract content (Barak & Hussein-Farra, 2013). It also transforms learning experiences from fragmented information into an ability to perceive relationships and systems, enabling students to connect biological concepts more deeply and durably (Malone, 2023; Wilson et al., 2020). Moreover, through the model-construction phase, students use and evaluate models on their own; comparing evidence obtained from designing scientific models or diagrams enables students to link ideas with understanding and develop conceptual understanding of the topic studied (Gilbert & Justi, 2016). Conversely, 16 students, representing 51.61%, remained at the Partial Understanding with Specific Alternative Conception (PS) or Alternative Conception (AC) level. Item-by-item analysis of the conceptual understanding assessment revealed that students had difficulties comprehending the content, and that their written responses consisted only of their selected answers without any accompanying reasoning, or provided explanations reflecting misconceptions about the phenomena studied, which affected their conceptual understanding scores. What teachers should consistently do to improve instructional effectiveness is to emphasize learner-centered active thinking through the instructional steps of Model-based learning (Göhner & Krell, 2022). The research team therefore added further processes in the next cycle to increase student participation, consistent with research showing that when sufficient time and a participation-conducive classroom structure are provided, biology learning outcomes improve significantly (Astiani et al., 2022; Naadhiroh et al., 2026; Pratiwi & Kusumadani, 2025).

Cycle 2: A total of 23 out of 31 students, representing 74.19%, reached the Complete Understanding (CU) or Partial Understanding

(PU) level, reflecting an increase from the previous cycle as evidenced by the greater number of students meeting the established criteria following instruction. Item-by-item analysis of the assessment also showed a marked decrease in student responses at the Partial Understanding with Specific Alternative Conception (PS) and Alternative Conception (AC) levels compared to Action Cycle 1 from 161 instances in Cycle 1 to 54 instances in Cycle 2. This improvement resulted from instructional adjustments that made the lesson more accessible to students during the evaluation and concept review phase, through questioning to check understanding and through questions that linked everyday life situations to the content being studied, enabling students to better grasp the key ideas of the lesson. This is consistent with the principle that sound scientific conceptual understanding develops through systematically connecting models to data, evidence, and reasoning, as well as with research indicating that learners should take an active role in proposing models, critiquing others' models, and collectively weighing explanations that best fit the available evidence (Yang et al., 2024). Model-based learning is most effective when teachers design appropriate activities and make model construction meaningful to learners; learner accessibility, diversity of representational formats, and connection to real phenomena are all important elements of effective teaching (Carroll & Park, 2026; Dahlquist, 2020; Louca & Zacharia, 2012). Nevertheless, 8 students, representing 25.81%, still did not meet the criteria, remaining at the PS or AC level. Analysis of the assessment revealed that some students still held misconceptions about the phenomena studied, wrote only their selected multiple-choice answers without providing reasoning, or misread test questions — for example, reading "which option is incorrect" as "which option is correct" resulting in lost marks. The research team planned to address this by incorporating additional activities, including supplementary video clips to deepen content understanding. This is consistent with key research principles showing that biology laboratory achievement is higher when students watch videos before and

after lab sessions, with scores in some cases doubling (Mutch-Jones et al., 2021); that in online biology classes, tutorial-style videos lead to better performance than traditional lecture-style videos, with the difference being most pronounced for higher-order thinking questions (Ding et al., 2024); and that secondary school biology scores improve when multimedia is incorporated as a supporting resource (Nihuka & Matem, 2024; Zhumash & Zhumagulova, 2025). For abstract or visually difficult topics, videos have been shown to elevate conceptual understanding of cell biology at the upper secondary level (Soltura, 2021), to reduce misconceptions about meiosis with conceptual understanding improving by 70% and misconceptions decreasing substantially (Sonam Dorji et al., 2025), and that using videos in conjunction with discovery learning raised mean scores from 53.4 to 85.3 (Trivena Patricia Sumual et al., 2025).

Cycle 3: All 31 students, representing 100.00%, reached the Complete Understanding (CU) or Partial Understanding (PU) level, demonstrating that every student met the established criteria and that scientific conceptual understanding had developed to a higher level. Item-by-item analysis of students' answers and reasoning revealed that all responses fell within the CU and PU levels. This may be attributed to the teacher's emphasis on instructional media including videos and animations which increased student engagement in learning activities. The use of media such as still images, videos, and physical specimens plays an important role in developing correct scientific

conceptual understanding, as it provides learners with concrete visual representations that facilitate learning and make conceptual understanding easier to attain (Soltura, 2021). Connecting real-life situations to the content being studied and using engaging introductory questions where questions that guide students toward conceptual understanding help strengthen knowledge connections (Dimitrova & Matthes, 2018) further contributed to the higher level of scientific conceptual understanding observed among students.

5. Conclusion

It can therefore be concluded that Model-based learning is capable of developing learners' scientific conceptual understanding. Across Action Cycles 1, 2, and 3, the numbers of students reaching the Complete Understanding (CU) or Partial Understanding (PU) level were 15, 23, and 31, respectively, indicating that each step of the learning management process progressively supported the development of students' scientific conceptual understanding. Model-based learning activities thus represent a viable instructional approach for helping students further develop their scientific conceptual understanding.

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7. Author Declaration

No conflicts of interest

References

- Amelia Fariza, Assha Uli Handayani Hasibuan, Eirene Carolina Simamora, M. Hafiz Ermawan, Nadya Shadrina Siregar, Nilam Mirzah, & Sister Imelda Lumban Gaol. (2025). Miskonsepsi Siswa Sekolah Dasar tentang Konsep IPA: Studi Kasus di kelas VI SDN 024755. *Jurnal Bintang Pendidikan Indonesia*, 3(2), 207–217. <https://doi.org/10.55606/jubpi.v3i2.3825>
- Astriani, M., Indriani, C., Hidayat, S., & Wardhani, S. (2022). ANALISIS PENERAPAN MODEL PEMBELAJARAN PADA KONDISI TATAP MUKA TERBATAS MATA PELAJARAN BIOLOGI DI MAN 1 PALEMBANG. *BIOEDUKASI (Jurnal Pendidikan Biologi)*, 13(1), 74. <https://doi.org/10.24127/bioedukasi.v13i1.5306>
- Barak, M., & Hussein-Farraj, R. (2013). Integrating Model-Based Learning and Animations for Enhancing Students' Understanding of Proteins Structure and Function. *Research in Science Education*, 43(2), 619–636. <https://doi.org/10.1007/s1727-735-727-735>

- Bryce, C. M., Baliga, V. B., De Nesnera, K. L., Fiack, D., Goetz, K., Tarjan, L. M., Wade, C. E., Yovovich, V., Baumgart, S., Bard, D. G., Ash, D., Parker, I. M., & Gilbert, G. S. (2016). Exploring Models in the Biology Classroom. *The American Biology Teacher*, 78(1), 35–42. <https://doi.org/10.1525/abt.2016.78.1.35>
- Carroll, G., & Park, S. (2026). Towards expansive model-based teaching: A systematic synthesis of modelling pedagogies in science education literature. *Studies in Science Education*, 62(1), 1–39. <https://doi.org/10.1080/03057267.2024.2417157>
- Dahlquist, K. D. (2020). An Invitation to Modeling. *The FASEB Journal*, 34(S1), 1–1. <https://doi.org/10.1096/fasebj.2020.34.s1.07048>
- Department of Educational Training The Islamia University of Bahawalpur Pakistan, Aziz, S., Akram, M., & Department of Educational Training The Islamia University of Bahawalpur Pakistan. (2022). DIAGNOSIS OF MISCONCEPTIONS IN BIOLOGY PART OF GENERAL SCIENCE BOOK: A CASE STUDY OF PRIMARY SCHOOL STUDENTS. *Pakistan Journal of Social Research*, 04(04), 800–808. <https://doi.org/10.52567/pjsr.v4i04.894>
- Dewi, E. P., & Wulandari, F. (2021). Identification of Misconceptions in Science Learning During the Covid-19 Pandemic Using the CRI (Certainty of Response Index) Method for Primary school Students. *Jurnal Penelitian Pendidikan IPA*, 7(SpecialIssue), 145–150. <https://doi.org/10.29303/jppipa.v7iSpecialIssue.876>
- Dimitrova, D. V., & Matthes, J. (2018). Social Media in Political Campaigning Around the World: Theoretical and Methodological Challenges. *Journalism & Mass Communication Quarterly*, 95(2), 333–342. <https://doi.org/10.1177/1077699018770437>
- Ding, L., Hung, K., & Zheng, H. (2024). Tutorial-Style Lecturing Video Instruction in an Online Biology Course: Responding to Evidence. *American Journal of Distance Education*, 38(2), 116–130. <https://doi.org/10.1080/08923647.2024.2303310>
- Ghina Dhaniyah Salsabil, Winda Sari, Ikmawati Ikmawati, & Kurniawan Kurniawan. (2024). Hakikat Sains: Pengertian, Fungsi, dan Penerapan dalam Proses Pembelajaran. *Populer: Jurnal Penelitian Mahasiswa*, 3(4), 37–45. <https://doi.org/10.58192/populer.v3i4.2664>
- Gilbert, J. K., & Justi, R. (2016). *Modelling-based Teaching in Science Education* (Vol. 9). Springer International Publishing. <https://doi.org/10.1007/727-735-727-735727-735>
- Göhner, M., & Krell, M. (2022). Preservice Science Teachers' Strategies in Scientific Reasoning: The Case of Modeling. *Research in Science Education*, 52(2), 395–414. <https://doi.org/10.1007/s1727-735-0727-735>
- Hasnawati, H., Syazali, M., & Widodo, A. (2022). Analysis of Understanding Science Concepts for Prospective Elementary School Teacher Candidates. *Jurnal Penelitian Pendidikan IPA*, 8(6), 2954–2960. <https://doi.org/10.29303/jppipa.v8i6.2438>
- Kamilah, D. S., Muki, B. G., Aviyanti, L., & Suhandi, A. (2025). Review of misconceptions in physics among Indonesian high school students: Diagnosis, causes, and remediation. *Momentum: Physics Education Journal*, 9(2), 251–263. <https://doi.org/10.21067/mpej.v9i2.11187>
- Kampourakis, K. (2018). On the Meaning of Concepts in Science Education. *Science & Education*, 27(7–8), 591–592. <https://doi.org/10.1007/s1727-735-0004-x>
- Laeli, C. M. H., Gunarhadi, & Muzzazinah. (2020). Misconception of Science Learning in Primary School Students. *Proceedings of the 3rd International Conference on Learning Innovation and Quality Education (ICLIQE 2019)*. Proceedings of the 3rd International Conference on Learning Innovation and Quality Education (ICLIQE 2019). <https://doi.org/10.2991/assehr.k.200129.083>
- Levytskyi, V., Radynskiy, S., & Dyachun, O. (2021). Economic education and science as the basis of innovative growth. *Socio-Economic Problems and the State*, 25(2), 474–481. <https://doi.org/10.33108/sepd2022.02.474>
- Louca, L. T., & Zacharia, Z. C. (2012). Modeling-based learning in science education: Cognitive, metacognitive, social, material and epistemological contributions. *Educational Review*, 64(4), 471–492. <https://doi.org/10.1080/00131911.2011.628748>
- Malone, K. L. (2023). The effects of modeling-based pedagogy on conceptual understanding, scientific reasoning skills, and attitudes towards science of English learners. *Science Education*, 107(5), 1269–1301. <https://doi.org/10.1002/sce.21805>

- Mutch-Jones, K., Sengupta, N., Minor, V. C., & Goudsouzian, L. K. (2021). Professional science education videos improve student performance in nonmajor and intermediate biology laboratory courses. *Biochemistry and Molecular Biology Education*, 49(1), 151–159. <https://doi.org/10.1002/bmb.21415>
- Naadhiroh, N. Z., Sunardi, S., & Sukmawati, F. (2026). Exploration of the Need for Developing ARCS Model-Based E-Module in Biology Learning: A Mixed-Methods Study. *Paedagogia: Jurnal Kajian, Penelitian Dan Pengembangan Kependidikan*, 17(2), 214. <https://doi.org/10.31764/paedagogia.v17i2.37679>
- Nihuka, K. A., & Matemu, F. P. (2024). Effectiveness of Offline Video-Based Biology Instructional Materials on Students' Performance in Secondary Schools. *HURIA JOURNAL OF THE OPEN UNIVERSITY OF TANZANIA*, 29(2). <https://doi.org/10.61538/huria.v29i2.1381>
- Pinto, T., & Teixeira, A. A. C. (2020). The impact of research output on economic growth by fields of science: A dynamic panel data analysis, 1980–2016. *Scientometrics*, 123(2), 945–978. <https://doi.org/10.1007/s1727-735-0727-735>
- Pratiwi, S., & Kusumadani, A. I. (2025). The Application of the Spirit of Socio-Scientific Problem-Based Learning (SSIPBL) Model to Improve Learning Outcomes on the Respiratory System Material at Senior High School. *Journal of Biology Learning*, 7(1), 9–14. <https://doi.org/10.32585/jbl.v7i1.6434>
- Satpayeva, Z. T., Moldabekova, A. T., & Mussayeva, D. M. (2020). The role of science in the socio-economic development of countries with different scientific potential. *Bulletin of "Turan" University*, (3), 223–228. <https://doi.org/10.46914/727-735-727-735-727-735-228>
- Sekaringtyas, T., Suyono, S., & Hadi, W. (2024). The Influence of Understanding Science Concepts, Critical Thinking Skills, and Scientific Literacy on Scientific Attitudes Class IV Primary School Students. *Journal of Ecohumanism*, 3(8). <https://doi.org/10.62754/joe.v3i8.5228>
- Soltura, R. T. (2021). Designing Context-Based Video Instruction in Enhancing the Conceptual Understanding of Grade XI Students. *Indonesian Journal Of Educational Research and Review*, 4(3), 409. <https://doi.org/10.23887/ijerr.v4i3.41635>
- Sonam Dorji, Sonam Wangchuk, Jigme Tshewang, & Kezang Jamtsho. (2025). Animation-Based Instruction to Eliminate the Misconception of Students in Learning Biology: An Action Research. *Educational Innovation and Practice*, 11(1), 53–71. <https://doi.org/10.17102/eip.11.2025.04>
- Trivena Patricia Sumual, Sukmarayu P. Gedoan, & Ferny M. Tumbel. (2025). Peningkatan Hasil Belajar Biologi Melalui Model Discovery Learning Berbasis Media Audio Visual. *Algoritma: Jurnal Matematika, Ilmu Pengetahuan Alam, Kebumihan Dan Angkasa*, 3(3), 93–107. <https://doi.org/10.62383/algoritma.v3i3.510>
- Utami, W. B., Dewi, A. P., & Widodo, S. A. (2024). STUDENTS' ERRORS IN PROBLEM-SOLVING REVIEWED FROM THE PERSPECTIVE OF MATH RESILIENCE. *JOHME: Journal of Holistic Mathematics Education*, 8(1), 59. <https://doi.org/10.19166/johme.v8i1.8230>
- Westbrook, S. L., & Marek, E. A. (1991). A cross-age study of student understanding of the concept of diffusion. *Journal of Research in Science Teaching*, 28(8), 649–660. <https://doi.org/10.1002/tea.3660280803>
- Wilson, K. J., Long, T. M., Momsen, J. L., & Bray Speth, E. (2020). Modeling in the Classroom: Making Relationships and Systems Visible. *CBE—Life Sciences Education*, 19(1), fe1. <https://doi.org/10.1187/cbe.727-735-0255>
- Yang, W., Chen, S., & Liu, C. (2024). Guiding Students in Constructing and Revising Models Rationally. *The American Biology Teacher*, 86(3), 130–135. <https://doi.org/10.1525/abt.2024.86.3.130>
- Zhumash, Zh., & Zhumagulova, K. A. (2025). THE EFFECTIVENESS OF INTEGRATED USE OF COMPUTER PROGRAMS AND VIDEO FILMS IN TEACHING SCHOOL BIOLOGY. *BULLETIN OF THE "NATURAL AND GEOGRAPHICAL SCIENCES" SERIES*, 83(1). <https://doi.org/10.51889/727-735.2025.83.1.006>