
Developing *Journey in Integria*: A web-based educational application for conceptual learning of integer operations

Rino Sinus Pandanu^{1*}

¹ Universitas Tanjungpura, Pontianak, Indonesia

*Corresponding Author: rinowarnawarni@gmail.com

Submission: 10 June 2026

Revision: 27 June 2026

Accepted: 7 July 2026

Abstract

Integer operation learning media are still predominantly based on static representations that provide limited support for students' conceptual understanding, while web-based instructional media integrating dynamic visualization and interactivity remain relatively limited. This study aims to develop *Journey in Integria*, a web-based educational application for learning integer operations using HTML, CSS, and JavaScript. The research employed the Luther-Sutopo multimedia development model consisting of *concept*, *design*, *material collecting*, *assembly*, *testing*, and *distribution*, while functional evaluation was conducted through *Black Box Testing*. The results demonstrate that the application successfully integrates dynamic number-line visualization, character animation, step-by-step solution logs, and interactive input features into a browser-based learning environment accessible across multiple devices without additional installation. All application functions operated according to the predefined specifications, and the application was successfully deployed through GitHub Pages for public access. This study contributes a web-based instructional medium that has the potential to support conceptual understanding of integer operations through integrated visualization and interactive learning experiences.

Keywords: Web development; Educational application; Multimedia; Integer operations; Educational technology.

Abstrak

Media pembelajaran operasi bilangan bulat umumnya masih didominasi oleh representasi statis sehingga kurang mampu memfasilitasi pemahaman konseptual, sementara pengembangan media berbasis web yang mengintegrasikan visualisasi dinamis dan interaktivitas masih relatif terbatas. Penelitian ini bertujuan mengembangkan aplikasi *Journey in Integria* sebagai media pembelajaran operasi bilangan bulat berbasis HTML, CSS, dan JavaScript. Penelitian menggunakan metode pengembangan multimedia Luther-Sutopo yang meliputi tahap *concept*, *design*, *material collecting*, *assembly*, *testing*, dan *distribution*, sedangkan pengujian dilakukan menggunakan *Black Box Testing*. Hasil penelitian menunjukkan bahwa aplikasi berhasil mengintegrasikan visualisasi garis bilangan, animasi karakter, log penyelesaian bertahap, serta panel input interaktif dalam satu platform berbasis web yang dapat diakses melalui berbagai perangkat tanpa instalasi tambahan. Seluruh fitur berfungsi sesuai spesifikasi yang dirancang dan aplikasi dipublikasikan melalui *GitHub Pages* sehingga siap dimanfaatkan sebagai media pembelajaran. Penelitian ini berkontribusi dengan menghadirkan media pembelajaran berbasis web yang berpotensi mendukung pemahaman konseptual operasi bilangan bulat melalui visualisasi dan interaktivitas yang terintegrasi.

Kata Kunci: Pengembangan web; Aplikasi pembelajaran; Multimedia; Operasi bilangan bulat; Teknologi pembelajaran.

Introduction

Mathematics is one of the fundamental subjects taught progressively from elementary to secondary education (Tong et al., 2022). Among the various topics covered, integer operations occupy a central position because they provide the foundation for understanding more advanced mathematical concepts, such as algebra, linear equations, and functions (Haavold & Sriraman, 2022). Mastery of integer operations is not only associated with computational proficiency but also reflects students' understanding of the relationships among numbers and their logical reasoning processes in solving mathematical problems (Schoenfeld, 2016). Therefore, conceptual understanding of integer operations constitutes an essential prerequisite before students engage with more abstract mathematical topics. Without a solid grasp of these fundamental concepts, students are likely to encounter difficulties when learning advanced mathematical content that requires higher-order reasoning skills.

Although integer operations represent a fundamental topic in mathematics education, numerous studies have reported that many students continue to experience difficulties in understanding the concepts of integer addition and subtraction (Ghoffar et al., 2025; Murdiana et al., 2022; Nabilla et al., 2025). One of the primary factors contributing to this problem is the continued reliance on instructional media such as textbooks, whiteboards, printed modules, and static number lines, which are unable to dynamically illustrate the movement between numerical positions (Anggraeni et al., 2020; Heryanto et al., 2022). Consequently, instruction tends to emphasize computational procedures rather than conceptual understanding. As a result, integer operations are often perceived as abstract concepts, leading students to memorize operational rules without fully understanding the mathematical reasoning underlying each computational process.

The rapid advancement of information technology has created new opportunities for educators to develop instructional media that are more interactive, engaging, and accessible to learners (Ghazy et al., 2025; Khotimah & Hafidz, 2025; Permana et al., 2024). One promising alternative is web-based educational applications that can be accessed through multiple devices without requiring additional software installation. Web technologies also enable the integration of animation, visualization, and real-time interaction, allowing abstract mathematical concepts to be presented in a more concrete and meaningful manner. Building upon this potential, *Journey in Integria* was developed as an educational application based on HTML, CSS, and JavaScript that integrates number-line visualization, character animation, an adventure-based narrative, and step-by-step procedural explanations. Through this approach, students are expected not only to obtain the correct answers but also to develop a deeper understanding of how the results of integer operations are generated.

Previous studies have explored the development of instructional media to enhance students' conceptual understanding of mathematics. Sumilat et al. (2022) developed computer-assisted instructional media for integer operations and demonstrated that multimedia effectively facilitates more engaging concept presentation. Murdiana et al. (2022) found that concrete instructional media effectively strengthen students' conceptual understanding of integer operations; however, their implementation remains dependent on physical manipulatives, thereby limiting instructional flexibility. Meanwhile, Khotimah and Hafidz (2025) highlighted the importance of developing creative instructional media based on information technology, whereas Zain (2021) emphasized the transformative role of interactive digital media in education. Nevertheless, these studies have not specifically developed a web-based educational application that integrates number-line visualization, character animation, an adventure-based narrative, and step-by-step procedural feedback into a single, comprehensive learning environment.

Based on these considerations, this study aims to develop *Journey in Integria*, an educational application based on HTML, CSS, and JavaScript, as an interactive instructional medium for learning integer operations that can be easily accessed through a web browser. The novelty of this study lies in integrating dynamic number-line visualization, character animation, an adventure-based storyline, and step-by-step procedural explanations into a single application, thereby shifting the instructional focus from merely obtaining correct answers to fostering comprehensive conceptual understanding. The development of this application is significant because it provides a more contextual, engaging, and technology-responsive alternative for mathematics instruction. Accordingly, this study is expected to produce a technically valid instructional media prototype while contributing to the promotion of more meaningful mathematics learning centered on students' conceptual understanding.

Method

This study employed the Luther-Sutopo (2003) multimedia development model because it is well suited for developing interactive educational applications that integrate text, graphics, animation, and user interaction within a single system. The model was selected because it provides a systematic development framework, beginning with concept formulation and ending with product distribution, thereby ensuring that each stage is implemented in a structured manner. The product developed in this study is *Journey in Integria*, a web-based educational application designed to assist elementary and junior high school students in understanding integer operations through number-line visualization, character animation, and interactive step-by-step procedural explanations. The application was developed using HTML to construct the page structure, CSS to design the user interface, and

JavaScript to manage the application logic and user interactions throughout the learning process.

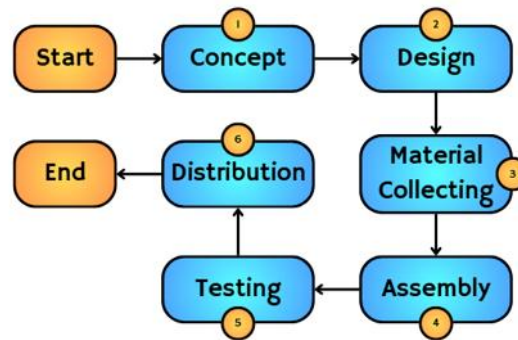


Figure 1. Luther-Sutopo multimedia development model

Source: Adapted from Sumilat et al. (2022).

As illustrated in Figure 1, the Luther-Sutopo model consists of six sequential stages: concept, design, material collecting, assembly, testing, and distribution. These six stages were systematically implemented in this study to ensure that each phase of the development process aligned with the established objectives. The activities performed at each stage are summarized in Table 1.

Table 1. Stages of the Luther-Sutopo multimedia development model

Stage	Main Activities
Concept	Determining the development objectives, target users, instructional content, and application specifications.
Design	Designing the application architecture, user interface, navigation flow, and storyboard.
Material Collecting	Collecting instructional materials, visual assets, fonts, and software required for the development process.
Assembly	Implementing the design by developing the application using HTML, CSS, and JavaScript.
Testing	Evaluating all application functions using the Black Box Testing method.
Distribution	Packaging and publishing the application through GitHub Pages for online access.

Source: Adapted from Sumilat et al. (2022).

Based on Table 1, the development process began with the concept stage, which focused on defining the instructional objectives, target users, and application specifications. The next stage, design, involved developing the user interface, application architecture, navigation flow, and storyboard to serve as implementation guidelines. Subsequently, the material collecting stage was conducted by gathering instructional materials on integer operations, visual assets, user interface components, and other supporting resources. These components were then integrated during the

assembly stage through programming with HTML, CSS, and JavaScript, resulting in a web-based educational application capable of providing interactive visualizations of integer operations while remaining accessible and easy to operate through a web browser.

Upon completion of the development process, the application was evaluated using the Black Box Testing method because it focuses on testing system functionality without examining the underlying source code (Ginting & Lubis, 2024; Jibril et al., 2024; Shadiq et al., 2021). The evaluation covered all major application functions, including numerical input, arithmetic operation selection, calculation processing, character animation on the number line, step-by-step solution display, navigation button functionality, and compatibility across different web browsers. Any discrepancies identified during the testing process were corrected until all application features operated according to the intended design specifications. The final stage, distribution, involved packaging the application and publishing it through GitHub Pages, enabling online access as a web-based instructional medium.

Results and Discussion

Journey in Integria as a web-based educational application for learning integer operations

Journey in Integria is a web-based educational application developed to help students understand the concept of integer operations through interactive visualization. The application is designed to run directly on various web browsers across desktop computers and mobile devices without requiring additional installation, making it more flexible for both classroom instruction and independent learning. The application was developed using HTML to structure the web pages, CSS to design the user interface, and JavaScript to manage the application logic and user interactions throughout the learning process. By integrating these three technologies, the application provides dynamic simulations of integer operations, enabling previously abstract mathematical concepts to be understood more concretely. The general specifications of the application are presented in Table 2.

Table 2. General specifications of *Journey in Integria*

Aspect	Specification
Application Name	<i>Journey in Integria</i>
Version	1.0
Application Type	Web-based interactive educational application
Platform	Desktop/laptop and smartphone web browsers
Programming Languages	HTML, CSS, JavaScript
Learning Topic	Integer Operations

Pandanu, Developing *Journey in Integria*

Target Users	Elementary and junior high school teachers and students
--------------	---

Source: Researcher's documentation (2026).

The *Journey in Integria* interface was designed using an adventure-based learning approach to enhance students' engagement throughout the learning process. As illustrated in Figure 2, the main interface consists of a number-line visualization area, the character Ellia Clarissa, an operation input panel, the *Cast Spell* button, the *Reset* button, a solution log, and the fundamental rules of integer operations. These components are systematically integrated, allowing users to observe the relationship between mathematical operations and positional changes on the number line in real time. This approach enables students not only to obtain the final answer but also to understand the movement of integers through animation and step-by-step explanations. The functions of the application's main components are summarized in Table 3.



Figure 2. Main interface of *Journey in Integria*

Source: Documentation of the *Journey in Integria* application (2026).

As shown in Figure 2, the *Journey in Integria* interface adopts a simple yet interactive layout that is intuitive for students to use. The number-line visualization serves as the primary instructional focus, while the operation input panel and navigation buttons are strategically positioned to facilitate intuitive interaction during the simulation process. The character Ellia Clarissa functions not merely as a visual element but also as a representation of numerical movement throughout each mathematical operation. In addition, the solution log and operational rules are presented simultaneously to help students understand the relationship between computational procedures and the underlying mathematical concepts. Consequently, each interface component serves not only a design function but also a pedagogical role in promoting students' conceptual understanding of integer operations.

Table 3. Functions of the main components of *Journey in Integria*

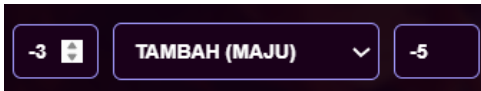
Component	Function
Number-line visualization	Displays the dynamic movement of numerical positions.
Ellia Clarissa character	Visualizes the direction and progression of movement along the number line.

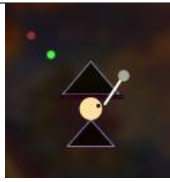
Operation input panel	Allows users to enter integers, select arithmetic operations, and execute simulations.
<i>Cast Spell</i> button	Executes the integer operation simulation.
<i>Reset</i> button	Restores the application to its initial state.
Solution log	Displays the solution process in sequential steps.
Operational rules	Provides guidance on the fundamental principles of integer operations.

Source: Researcher's documentation (2026).

The implementation of *Journey in Integria* integrates instructional content, visual assets, and web technologies into a unified educational application. The instructional materials on integer operations were developed based on the current curriculum and combined with a fantasy-themed background, the character Ellia Clarissa, user interface components, and decorative typography to create a more engaging learning experience. These elements were implemented using HTML, CSS, and JavaScript, resulting in an application capable of presenting dynamic number-line visualization, character animation, automated calculations, and step-by-step solution logs. The integration of these components enables students to understand the relationship between mathematical operations and positional changes on the number line through a more interactive learning experience. The visual representation and description of each application component are presented in Table 4.

Table 4. Visual representation and description of *Journey in Integria* components

Component	Component Image	Component Explanation
Main Page		The comprehensive visual layout of the application.
Number Line Visualization		A number line featuring the number zero highlighted in a distinct color to denote the midpoint.
Operation Input		The section where users input two integers and select the desired mathematical operation.

Component	Component Image	Component Explanation
Character (Ellia Clarissa)		A simplified representation of the character Ellia Clarissa, constructed from two-dimensional geometric shapes arranged to resemble a witch.
Log		In the adjacent image, an example is provided demonstrating how the web application computes $-3 + -5$. The log section functions to explicitly illustrate the procedural steps of the operation.
Rules		The guidelines articulating how the functioning operations are analogized.

Source: Researcher's documentation (2026).

The application was subsequently evaluated using the Black Box Testing method to ensure that every function operated according to the predefined specifications (Ginting & Lubis, 2024; Jibril et al., 2024; Shadiq et al., 2021). The evaluation covered all core application features, including numerical input, addition and subtraction operations, character animation, the solution log, and the reset function. The testing results indicated that all features functioned correctly without any functional errors. As presented in Table 5, each testing scenario produced outputs consistent with the intended design, while the screenshot column provides visual evidence demonstrating that every feature operated as expected.

Table 5. Black box testing results of *Journey in Integra*

Tested Function	Input	Output	Result	Screenshot
Number input	-5 and 10	Displayed	Valid	
Addition operation	$-5 + 10$	Result of 5	Valid	
Subtraction operation	$-5 - 10$	Result of -15	Valid	

Tested Function	Input	Output	Result	Screenshot
Character animation	Visible	Moves	Valid	
				
Process log	Appears	Accurate	Valid	
Reset	Click	Resets	Valid	
				

Source: Researcher's testing documentation (2026).

The development results demonstrate that *Journey in Integria* successfully integrates number-line visualization, character animation, and step-by-step solution presentation into a web-based educational application that can be accessed across multiple devices. This integration produces an instructional medium that not only presents the results of integer operations but also visualizes the solution process, enabling students to develop a more concrete understanding of mathematical concepts. All application functions operated according to the predefined specifications and were subsequently deployed through GitHub Pages, allowing online access without requiring additional software installation. The application is publicly available at <https://rino-sinus-pandanu.github.io/Journey-In-Integria/>, providing

teachers and students with convenient access to a web-based instructional medium for both classroom instruction and independent learning.

Although the functional evaluation confirmed that all application features performed according to the intended specifications, the findings remain limited to the technical performance of the application. The present study did not evaluate the effectiveness of *Journey in Integria* in improving students' conceptual understanding of integer operations or their learning experiences. Therefore, further analysis is required to examine the application's pedagogical characteristics, its advantages over conventional instructional media, its alignment with learning theories, and its remaining limitations. Such analysis is essential for providing a more comprehensive understanding of the potential of *Journey in Integria* as an instructional medium for learning integer operations and for evaluating its contribution to mathematics education.

Pedagogical characteristics of Journey in Integria in supporting conceptual learning of integer operations

The rapid advancement of educational technology has led to the emergence of numerous digital instructional media equipped with a wide range of interactive features (Alam & Mohanty, 2023). However, technological innovation has not always been accompanied by improvements in conceptual learning. Many digital learning media successfully attract students' attention through visually appealing interfaces, yet they remain primarily oriented toward delivering correct answers rather than facilitating students' mathematical reasoning processes (Hoyles, 2018). Consequently, the digitalization of education often transforms only the mode of content delivery without fundamentally improving how students construct conceptual understanding (Reyna et al., 2018). Therefore, the quality of instructional media should not be judged solely by technological sophistication but by the extent to which its pedagogical characteristics facilitate conceptual learning. This perspective provides the foundation for analyzing *Journey in Integria* as an instructional medium for learning integer operations.

Table 6. Pedagogical characteristics of *Journey in Integria* and their instructional implications

Application Characteristic	Development Findings	Instructional Implications
Dynamic number-line visualization	Displays the movement of integers through real-time visual simulation.	Helps students connect integer operations with concrete representations.
Character animation	The character moves according to addition and subtraction operations.	Facilitates understanding of the direction of positive and negative integer movement.

Step-by-step solution log	The solution process is presented sequentially before displaying the final answer.	Supports both procedural and conceptual understanding.
Interactive input panel	Users can independently select integers and arithmetic operations for simulation.	Encourages self-exploration and active learning.
Web-based accessibility	The application runs on multiple devices without requiring installation.	Facilitates implementation across various learning environments.
Black Box Testing results	All core application functions operated according to the intended specifications.	Demonstrates the application's readiness for instructional use.

Source: Researcher's analysis (2026).

The most distinctive characteristic of *Journey in Integria* is its integration of dynamic number-line visualization with character animation, allowing every addition and subtraction process to be observed directly. As summarized in Table 6, visualization serves not merely as a graphical feature but as a pedagogical tool that illustrates the relationship between mathematical operations and positional changes on the number line. This approach enables students to develop concrete mental representations before progressing to symbolic reasoning. Such an instructional strategy is consistent with Bruner's theory of representation, which emphasizes visualization as an essential stage in conceptual development. García-Bayona et al. (2025) similarly found that visual-based instructional media reduce the abstract nature of mathematical concepts. Unlike previous visual media, however, *Journey in Integria* incorporates dynamic animation, enabling students to observe numerical movement continuously throughout the operational process.

Another pedagogically significant characteristic of *Journey in Integria* is the integration of a step-by-step solution log with an interactive input panel. According to the development findings, the application does not immediately display the final answer; instead, it presents each stage of the computational process before arriving at the correct result. This design encourages students to understand the mathematical reasoning underlying integer operations rather than simply memorizing computational rules. At the same time, the interactive input panel enables learners to experiment with different combinations of integers independently, promoting exploration-based learning. This instructional approach is consistent with Fazio (2020), who emphasized the importance of active student engagement in developing conceptual understanding. It also extends the work of Lodge et al. (2018), whose interactive learning media emphasized learner engagement but did not incorporate continuous procedural feedback throughout the learning process.

Another feature that strengthens the instructional potential of *Journey in Integria* is its accessibility across multiple devices without requiring software installation. The development results demonstrate that the application can be accessed through web browsers on both desktop computers and smartphones, requiring only an internet connection to utilize all available features. This accessibility provides teachers with greater flexibility to integrate the application into various instructional settings, including classroom instruction, computer laboratories, and independent learning at home. Such flexibility is consistent with the findings of Guzmán and Joseph (2021), who argued that web-based instructional media broaden learning opportunities because they are not restricted to a particular operating system. Similarly, Sayaf et al. (2021) highlighted ease of access as a key factor influencing the sustained adoption of digital instructional media. Therefore, the value of *Journey in Integria* extends beyond its interactive features to include its practical implementation across diverse educational contexts.

To provide a more comprehensive evaluation, the characteristics of *Journey in Integria* can be compared with those of conventional instructional media commonly used to teach integer operations. This comparison indicates that the application represents more than a simple digital transformation of printed instructional materials; instead, it offers a richer learning experience by integrating visualization, animation, and procedural feedback into a unified instructional environment. A summary of this comparison is presented in Table 7.

Table 7. Comparison between *Journey in Integria* and conventional instructional media

Aspect	Conventional Instructional Media	<i>Journey in Integria</i>
Concept presentation	Primarily based on text and worked examples	Integrates visualization, animation, and interactive simulation
Representation of operations	Static number lines or classroom illustrations	Dynamic number-line visualization with character animation
Learning process	Teacher-centered instruction	Encourages independent exploration
Feedback	Typically provided after problem completion	Delivered immediately through the solution log
Accessibility	Limited to classroom settings and printed materials	Accessible through web-enabled devices

Source: Researcher's analysis (2026).

As presented in Table 7, the most fundamental distinction lies in how the concept of integer operations is represented to students. Conventional instructional media generally rely on teacher explanations and static illustrations, whereas *Journey in Integria* dynamically visualizes numerical movement, allowing students to observe the relationship between arithmetic operations and positional changes on the number line.

This finding suggests that educational digitalization should involve not only changes in instructional media but also improvements in the pedagogical approaches used to communicate mathematical concepts. Moran et al. (2019) similarly concluded that interactive instructional media are more effective than static media in supporting conceptual representation. Nevertheless, *Journey in Integria* offers an additional contribution by integrating dynamic visualization with step-by-step procedural feedback, a combination that remains relatively uncommon in existing instructional media for learning integer operations.

Despite its pedagogical strengths, this study has several limitations. The evaluation focused exclusively on functional performance through Black Box Testing, meaning that the findings confirm only that all application features operated according to the intended specifications. The study did not examine how the use of *Journey in Integria* influences students' conceptual understanding, learning motivation, or academic achievement in authentic classroom settings. Therefore, future research should involve experimental or quasi-experimental designs to evaluate the educational effectiveness of the application empirically. Such investigations would provide stronger evidence regarding the contribution of *Journey in Integria* as a web-based mathematics learning application while also informing the development of more adaptive features that better accommodate learners' diverse instructional needs.

Conclusion

This study developed *Journey in Integria*, a web-based educational application for learning integer operations that integrates number-line visualization, character animation, an interactive input panel, a step-by-step solution log, and operational rules within a unified learning environment. The application was developed using HTML, CSS, and JavaScript based on the Luther-Sutopo multimedia development model, while its functional performance was validated through Black Box Testing. The evaluation results demonstrated that all application features operated according to the intended specifications, indicating that the application is technically ready for instructional use. By integrating these pedagogical characteristics, *Journey in Integria* functions not only as a computational tool but also as an instructional medium that concretely visualizes the process of performing integer operations. Consequently, the application has the potential to support students' conceptual understanding by presenting mathematical processes in a more interactive, visual, and accessible manner than conventional instructional approaches.

This study contributes to the development of mathematics instructional media by introducing a web-based educational application that combines dynamic visualization, interactivity, and accessibility within a single platform, thereby expanding the range of digital learning resources available for teaching integer operations. Nevertheless, the study is limited to product development and functional

evaluation and therefore does not examine the application's effectiveness in improving students' conceptual understanding, learning motivation, or academic achievement. Future research should incorporate experimental or quasi-experimental designs involving students to evaluate the educational impact of *Journey in Integria* on learning processes and outcomes. Furthermore, the integration of adaptive learning features, the inclusion of additional mathematics topics, and the implementation of more comprehensive gamification elements represent promising directions for future development to further enhance the quality and educational value of the application across diverse learning contexts.

References

- Alam, A., & Mohanty, A. (2023). Educational technology: Exploring the convergence of technology and pedagogy through mobility, interactivity, AI, and learning tools. *Cogent Engineering*, 10(2). <https://doi.org/10.1080/23311916.2023.2283282>
- Anggraeni, S. T., Muryaningsih, S., & Ernawati, A. (2020). Analisis faktor penyebab kesulitan belajar matematika di sekolah dasar. *JRPD: Jurnal Riset Pendidikan Dasar*, 1(1), 25–37. <https://doi.org/10.30595/.v1i1.7929>
- Fazio, C. (2020). Active learning methods and strategies to improve student conceptual understanding: Some considerations from physics education research. In *Research and innovation in physics education: Two sides of the same coin* (pp. 15–35). https://doi.org/10.1007/978-3-030-51182-1_2
- García-Bayona, I., Pérez-Suay, A., Van Vaerenbergh, S., & Pascual-Venteo, A. B. (2025). Exploring the influence of visual aids in mathematical problem solving: An eye-tracking study with prospective teachers. *IEEE Transactions on Education*, 68(6), 553–567. <https://doi.org/10.1109/TE.2025.3626625>
- Ghazy, A. C., Ghozali, & Wibowo, K. A. (2025). Transformasi pendidikan: Pengembangan metodologi dan media pembelajaran di era digital. *ARJI: Action Research Journal Indonesia*, 7(4), 2975–2997. <https://journal.nahnuinisiatif.com/ARJI/article/view/594>
- Ghoffar, M., Wiryanto, & Rahaju, E. B. (2025). Profil belajar siswa dalam memahami operasi hitung bilangan bulat kelas VI sekolah dasar. *Edukasi: Jurnal Penelitian & Artikel Pendidikan*, 17(1), 633–646. <https://doi.org/10.31603/edukasi.v17i1.13349>
- Ginting, M. P. A., & Lubis, A. S. (2024). Pengujian aplikasi berbasis web data SKA menggunakan metode black box testing. *Cosmic Jurnal Teknik*, 2(1), 41–48. <https://journal.aira.or.id/cosmic/article/view/760>
- Guzmán, J. L., & Joseph, B. (2021). Web-based virtual lab for learning design, operation, control, and optimization of an anaerobic digestion process. *Journal of*

- Science Education and Technology*, 30(3), 319–330. <https://doi.org/10.1007/s10956-020-09860-6>
- Haavold, P. Ø., & Sriraman, B. (2022). Creativity in problem solving: Integrating two different views of insight. *ZDM – Mathematics Education*, 54(1), 83–96. <https://doi.org/10.1007/s11858-021-01304-8>
- Heryanto, Sembiring, S. B., & Togatorop, J. B. (2022). Analisis faktor penyebab kesulitan belajar matematika siswa kelas V sekolah dasar. *Curere*, 6(1), 45–54. <https://doi.org/10.36764/jc.v6i1.723>
- Hoyles, C. (2018). Transforming the mathematical practices of learners and teachers through digital technology. *Research in Mathematics Education*, 20(3), 209–228. <https://doi.org/10.1080/14794802.2018.1484799>
- Jibril, M., Zulrahmadi, & Amin, M. (2024). Pengujian sistem informasi e-modul pada SMPN 1 Tempulung menggunakan black box testing. *Jurnal Perangkat Lunak*, 6(2), 327–332. <https://jurnalfitik.unisi.ac.id/index.php/jupel/article/view/3326>
- Khotimah, D. F. K., & Hafidz. (2025). Pengembangan media pembelajaran kreatif dan interaktif melalui teknologi informasi dan komunikasi (TIK) dalam pendidikan. *IHSAN: Jurnal Pendidikan Islam*, 3(1), 1–8. <https://doi.org/10.61104/ihsan.v3i1.433>
- Lodge, J. M., Kennedy, G., Lockyer, L., Arguel, A., & Pachman, M. (2018). Understanding difficulties and resulting confusion in learning: An integrative review. *Frontiers in Education*, 3. <https://doi.org/10.3389/feduc.2018.00049>
- Moran, G., Muzellec, L., & Johnson, D. (2019). Message content features and social media engagement: Evidence from the media industry. *Journal of Product & Brand Management*, 29(5), 533–545. <https://doi.org/10.1108/JPBM-09-2018-2014>
- Murdiana, I. N., Sukayasa, & Hasbi, M. (2022). Pelatihan penggunaan media kongkret dalam penanaman konsep pada operasi hitung bilangan bulat. *Jurnal Kreatif Online*, 10(1), 13–26. <https://jurnalfkipuntad.com/index.php/jko/article/view/1915>
- Nabilla, R., Lestari, D. A., Hafizah, I., Fendrik, M., & Oktaviani, C. (2025). Analisis kesulitan siswa dalam memahami operasi bilangan bulat di kelas VI SDN 41 Pekanbaru. *Jurnal Terapan Pendidikan Dasar dan Menengah*, 5(4), 264–270. <https://ojs.unublitar.ac.id/index.php/jtpdm/article/view/2268>
- Permana, R., Syakur, I., Nugroho, A. R., & Kurniawan, B. A. (2024). Analisis penggunaan machine learning untuk deteksi penipuan di sektor keuangan: Tinjauan literatur. *TEKNOBIS : Teknologi, Bisnis Dan Pendidikan*, 2(2), 244–248. <https://jurnalmahasiswa.com/index.php/teknobis/article/view/2074>

- Reyna, J., Hanham, J., & Meier, P. C. (2018). A framework for digital media literacies for teaching and learning in higher education. *E-Learning and Digital Media*, 15(4), 176–190. <https://doi.org/10.1177/2042753018784952>
- Sayaf, A. M., Alamri, M. M., Alqahtani, M. A., & Al-Rahmi, W. M. (2021). Information and communications technology used in higher education: An empirical study on digital learning as sustainability. *Sustainability*, 13(13), 7074. <https://doi.org/10.3390/su13137074>
- Schoenfeld, A. H. (2016). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics (Reprint). *Journal of Education*, 196(2), 1–38. <https://doi.org/10.1177/002205741619600202>
- Shadiq, J., Safei, A., & Loly, R. W. R. (2021). Pengujian aplikasi peminjaman kendaraan operasional kantor menggunakan blackbox testing. *Information Management for Educators and Professionals*, 5(2), 97–110. <https://doi.org/10.51211/imbi.v5i2.1561>
- Sumilat, J. M., Tumurang, H. J., Suleman, G., & Posumah, N. (2022). Development of computer-aided media operating materials calculate integers. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, 12(1), 103–110. <http://dx.doi.org/10.30998/formatif.v12i1.11543>
- Sutopo, A. H. (2003). *Multimedia interaktif dengan flash*. Graha Ilmu.
- Tong, D. H., Uyen, B. P., & Ngan, L. K. (2022). The effectiveness of blended learning on students' academic achievement, self-study skills and learning attitudes: A quasi-experiment study in teaching the conventions for coordinates in the plane. *Heliyon*, 8(12), e12657. <https://doi.org/10.1016/j.heliyon.2022.e12657>
- Zain, S. (2021). Digital transformation trends in education. In *Future directions in digital information* (pp. 223–234). Elsevier. <https://doi.org/10.1016/B978-0-12-822144-0.00036-7>