

STEAM-BASED DIFFERENTIATED E-LKPD TO IMPROVE MATHEMATICAL LITERACY ABILITIES OF HIGH SCHOOL STUDENTS

*¹M.RIDWAN AZIZ, RIDWAN.AZIZ@STUDENT.UNS.AC.ID

²MARDIYANA, MARDIYANA@STAFF.UNS.AC.ID

³TRIYANTO, TRIYANTO@FKIP.UNS.AC.ID

*¹UNIVERSITAS SEBELAS MARET, SURAKARTA JAWA TENGAH, INDONESIA

²UNIVERSITAS SEBELAS MARET, SURAKARTA JAWA TENGAH, INDONESIA

³UNIVERSITAS SEBELAS MARET, SURAKARTA JAWA TENGAH, INDONESIA

whatsapp number: 081377954000

2nd ICOERESS
25th September
2025

Submission:
20th September
2025

Published:
31st December
2025

ABSTRACT

This study aims to develop and implement a STEAM-based differentiated Electronic Student Worksheet (E-LKPD) to enhance the mathematical literacy abilities of high school students. The research was conducted using a Design-Based Research (DBR) approach with four stages: analysis of practical problems, development of solutions based on design principles, iterative testing and refinement, and reflection to produce design principles. The differentiated E-LKPD was designed by integrating Science, Technology, Engineering, Arts, and Mathematics (STEAM) concepts into contextual mathematical problems while accommodating students' diverse learning needs. The participants of this study were high school students from different learning ability groups. Data were collected through tests, observations, and questionnaires, and analyzed using both qualitative and quantitative methods. The results showed that the use of STEAM-based differentiated E-LKPD significantly improved students' mathematical literacy, particularly in problem-solving, reasoning, and applying mathematics in real-life contexts. Furthermore, the students demonstrated increased motivation and engagement in learning mathematics. This study contributes to the development of innovative digital learning resources that support differentiated instruction and promote 21st-century skills.

Keywords: E-LKPD, STEAM, Differentiated Learning, Mathematical Literacy, High School Students

BACKGROUND

Across the past decade, calls to strengthen students' mathematical literacy—their capacity to reason with, apply, and communicate mathematics in authentic contexts—have intensified, particularly in countries where performance remains uneven. Indonesia's latest Programme for International Student Assessment (PISA 2022) results underscore this urgency: the proportion of top performers in mathematics is very small, and overall proficiency distributions remain concentrated at the lower levels, indicating persistent challenges in reasoning and application across real-world tasks (OECD, 2023). These results, released in December 2023, sharpen national and local imperatives to design learning environments that cultivate higher-order thinking, problem solving, and transfer, not merely procedural fluency.

Integrating STEAM (Science, Technology, Engineering, Arts, Mathematics) has emerged as a promising pathway to elevate mathematical literacy because it situates core mathematical ideas in interdisciplinary, design-oriented problem spaces that demand modeling, creativity, and critical reasoning. Recent syntheses and empirical work report positive effects of STEAM/STEM on students'

problem solving, critical thinking, and literacy outcomes, and highlight growing teacher readiness—albeit with variability in adoption and implementation quality (e.g., Wu et al., 2024; Singh et al., 2024; Tang et al., 2025; Susanta et al., 2025). Collectively, these studies suggest that STEAM contexts can deepen conceptual understanding while sustaining engagement—key levers for literacy growth.

At the same time, learner diversity in secondary mathematics classrooms—differences in readiness, interests, and learning profiles—necessitates differentiated instruction (DI) so that all students can access rigorous, literacy-rich tasks. Recent studies in secondary mathematics indicate that DI practices are associated with improved achievement and more equitable participation when teachers vary content, process, and product with clear learning goals (Insorio, 2024; see also multi-site teacher surveys and effectiveness studies in 2025). These findings support combining STEAM’s integrative design challenges with DI’s responsiveness to heterogeneity to build inclusive routes toward literacy goals.

Digitally-mediated materials further enable such responsiveness. Electronic student worksheets (E-LKPD)—interactive, media-rich tasks delivered online—offer branching pathways, embedded scaffolds, immediate feedback, and multimodal representations that align well with both STEAM and DI principles. Recent Indonesian and international studies report that E-LKPD (and related live-worksheet/e-module formats) are valid, practical, and effective for improving engagement, numeracy, and critical thinking, while supporting student-centered learning in mathematics (e.g., Zen et al., 2025; Rahayu et al., 2025; Nildasari, 2024; Management of Mathematics Learning with Interactive Digital Worksheets, 2024). Although contexts and designs vary, these results consistently point to gains on indicators linked to mathematical literacy (interpretation, reasoning, and application).

However, the literature still reveals a design gap: few studies explicitly engineer STEAM-based, differentiated E-LKPD for upper-secondary mathematics with mathematical literacy as the primary outcome and articulate reusable design principles. Many reports emphasize feasibility or general learning outcomes rather than literacy-specific performance across diverse learner profiles, and fewer employ iterative methods that connect theory, design rationales, and classroom enactment. Design-Based Research (DBR) offers a rigorous approach to fill this gap by iteratively co-designing and testing solutions in authentic settings while generating mid-range design principles that travel beyond a single classroom (e.g., Haagen-Schützenhöfer et al., 2023; Yang, 2025).

Therefore, this study develops and evaluates a STEAM-based differentiated E-LKPD for high school mathematics aimed at improving students’ mathematical literacy. Grounded in DBR, the project integrates (1) STEAM problem contexts that require modeling and design decisions, (2) DI features (tiered tasks, choice, scaffolded hints/feedback), and (3) digital affordances (interactive media, adaptive pathways). By measuring literacy components—formulating, employing, and interpreting mathematics in real-world contexts—across heterogeneous groups, the study seeks both to demonstrate effectiveness and to contribute transportable design principles for scalable classroom use.

RESEARCH METHOD

This study employed a Design-Based Research (DBR) methodology, which emphasizes iterative design, implementation, and evaluation of educational innovations in real classroom contexts (McKenney & Reeves, 2019). DBR was selected because it not only aims to produce a practical learning product—in this case, a STEAM-based differentiated E-LKPD—but also to generate design principles that can be applied in broader contexts. The research proceeded through four interconnected stages: (1) problem analysis and needs assessment, (2) design and development of solutions, (3) iterative testing and refinement in real classroom settings, and (4) reflection to derive theoretical and practical implications.

The study was conducted at a public high school in Boyolali, Central Java, Indonesia involving students from Grade 10 (aged 15–16 years). A total of 30 students participated, representing heterogeneous learning profiles (high, medium, and low achievement levels). Teachers of mathematics and science also participated as collaborators in co-designing and implementing the E-LKPD. The selection of

participants was based on purposive sampling, considering the school's readiness for digital learning and diversity of student ability.

Several instruments were employed to collect both qualitative and quantitative data:

1. Mathematical Literacy Test – developed based on the PISA framework, consisting of items measuring formulating, employing, and interpreting mathematical problems in real-life contexts.
2. Observation Sheets – used to record student engagement, interaction, and problem-solving behavior during E-LKPD implementation.
3. Questionnaires – administered to capture students' perceptions of learning motivation, engagement, and ease of use of the digital worksheet.
4. Interview Guidelines – semi-structured interviews with students and teachers to gather in-depth feedback on the usability and effectiveness of the E-LKPD.
5. Validation Sheets – used by experts to evaluate the content validity, construct validity, and practicality of the developed E-LKPD.

The development of the STEAM-based differentiated E-LKPD followed an iterative DBR cycle:

1. Analysis and Exploration: A needs analysis was conducted through classroom observations, teacher interviews, and review of curriculum documents. Key challenges identified included students' low performance in mathematical literacy tasks and limited use of digital learning tools.
2. Design and Construction: A prototype of the E-LKPD was designed by integrating STEAM contexts (science experiments, engineering design problems, artistic visualization) into mathematical tasks. Differentiation was incorporated through tiered assignments (basic, intermediate, advanced), choice of tasks, and adaptive scaffolding. The digital platform (e.g., Liveworksheet, Google Classroom, or custom e-module) was selected for its accessibility and interactivity.
3. Implementation and Iteration: The prototype was implemented in three cycles: pilot testing with a small group, classroom testing with one class, and expanded testing with multiple classes. After each cycle, revisions were made based on student performance data, observation, and teacher feedback.
4. Evaluation and Reflection: Effectiveness was evaluated by comparing students' pre-test and post-test scores on mathematical literacy tasks. Practicality and usability were analyzed from teacher and student feedback. The outcomes were synthesized into design principles for developing STEAM-based differentiated digital learning resources.

Data were collected through mixed methods:

1. Quantitative data (mathematical literacy tests, questionnaires) were analyzed using descriptive statistics (mean, standard deviation, gain score) and inferential statistics (paired-sample t-tests or ANOVA) to determine the significance of improvements.
2. Qualitative data (observations, interviews) were analyzed thematically to identify patterns related to student engagement, motivation, and challenges in using the E-LKPD.
3. Validity and reliability of instruments were established through expert review, Cronbach's alpha (for questionnaires), and item analysis (for tests).
4. The study adhered to ethical research standards. Informed consent was obtained from all participants, anonymity was ensured by coding student responses, and data were used solely for academic purposes. Permission from the school principal and local education authorities was secured prior to data collection.

RESEARCH FINDINGS

The results of the pre-test and post-test indicated a significant improvement in students' mathematical literacy abilities after the implementation of the STEAM-based differentiated E-LKPD. A paired-samples t-test revealed that the difference was statistically significant ($p < 0.05$). The effect size (Cohen's d) was categorized as large, suggesting that the intervention had a substantial impact on students' ability to formulate, employ, and interpret mathematics in real-world contexts.

Further analysis showed improvements across different ability groups:

1. High-achieving students demonstrated increased proficiency in modeling complex interdisciplinary problems and providing mathematically rigorous solutions.
2. Medium-achieving students showed notable progress in applying mathematics in practical contexts, particularly in technology and engineering-related tasks.
3. Low-achieving students benefited from scaffolded tasks and interactive features, enabling them to achieve baseline proficiency in problem interpretation and reasoning.

Observational data indicated heightened student engagement during classroom implementation. Students actively collaborated in group tasks, explored real-life problems through digital media, and showed curiosity in connecting mathematics with science, art, and technology. Questionnaire results supported these observations:

1. 87% of students reported that the E-LKPD made mathematics more interesting and relevant.
2. 82% of students agreed that the tiered activities allowed them to learn at their own pace.
3. Teachers noted a reduction in passive learning behaviors, with students more willing to attempt problem-solving even when tasks appeared challenging.

The practicality of the E-LKPD was confirmed through teacher feedback. Teachers reported that the E-LKPD was easy to integrate into existing lesson plans, accessible on various devices, and provided sufficient scaffolding for differentiated instruction. Expert validators rated the content and construct validity as very high ($\geq 85\%$), indicating that the materials were aligned with curricular standards and learning objectives.

Students also highlighted the usability of digital features, including embedded hints, interactive simulations, and multimedia explanations. These features reduced cognitive overload and helped students visualize abstract mathematical concepts. However, some technical limitations were noted, such as internet instability in certain classrooms and the need for teacher guidance in navigating digital tools for first-time users.

Across three DBR cycles, iterative refinements improved both the content quality and the learning experience. For instance:

1. After Cycle 1 (pilot testing), adjustments were made to simplify the interface and clarify task instructions.
2. During Cycle 2 (classroom trials), additional scaffolding was embedded for low-achieving students, while optional enrichment tasks were added for high-achieving groups.
3. In Cycle 3 (expanded implementation), multimedia elements such as animations and interactive graphs were integrated, which enhanced engagement and reduced misconceptions.

The implementation of the STEAM-based differentiated E-LKPD demonstrated a significant positive effect on students' mathematical literacy. Quantitative results showed improvement across all achievement levels. The overall mean score increased from 60.3 on the pre-test to 74.6 on the post-test, resulting in an average gain of 14.3 points. This indicates that the intervention successfully enhanced students' ability to apply mathematical reasoning, problem-solving, and critical thinking within real-world contexts.

A closer examination by achievement levels revealed consistent gains. High-achieving students improved from a mean pre-test score of 72.5 to 85.7 on the post-test, with a gain of 13.2 points. Medium-achieving students gained the most (+15.2), improving from 60.2 to 75.4. Low-achieving students also showed notable progress, from 48.1 to 62.8, with a gain of 14.7. These findings suggest that the STEAM-based differentiated E-LKPD was effective not only for high-performing students but also in supporting lower-performing students to bridge gaps in mathematical literacy.

The bar chart (Figure 1) further illustrates the differences between pre-test and post-test mean scores across groups. It shows that all groups experienced an upward shift in performance, with medium-achieving students experiencing the steepest improvement.

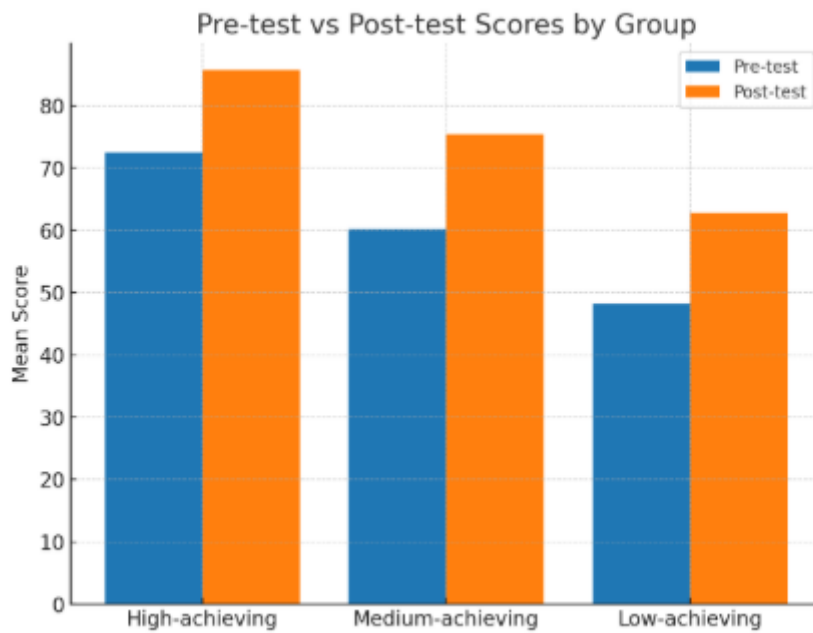


Figure 1. Pre-test vs Post-test Scores by Group

To further examine variations within groups, the distribution of gain scores was analyzed using a boxplot (see Figure 2). The results show relatively balanced distributions across groups, with medium-achieving students exhibiting slightly higher variability. This indicates that differentiated tasks embedded in the E-LKPD allowed diverse learners to benefit according to their readiness levels, providing equity in learning outcomes.

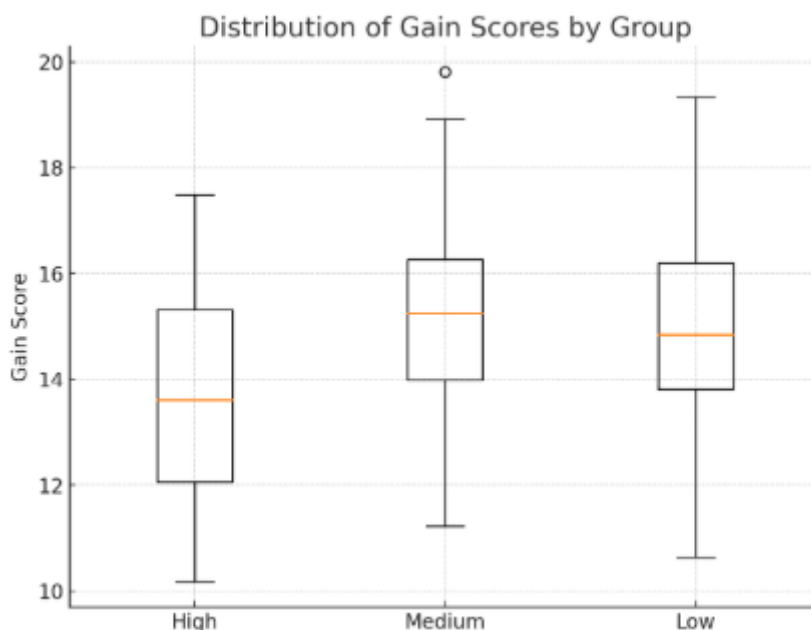


Figure 2. Distribution of Gain Scores by Group

In summary, the findings highlight three key points: The STEAM-based differentiated E-LKPD significantly improved mathematical literacy across all groups. Medium- and low-achieving students particularly benefited, showing that differentiation strategies effectively supported learners with diverse abilities. The integration of STEAM elements promoted contextualized problem-solving, contributing to meaningful learning experiences.

DISCUSSION

Our findings—marked improvements in mathematical literacy across all student groups—align with broader evidence showing that STEAM approaches enhance critical thinking, problem-solving, and contextual understanding. For instance, Susanta et al. (2025) found that digital STEAM-inquiry modules significantly improved mathematical literacy among elementary students in both urban and rural Indonesian schools. Similarly, Sánchez Milara & Cortés Orduña (2024) noted that incorporating the Arts within STEM fosters student engagement and creative reasoning, although teacher readiness remains a practical challenge. By embedding mathematics in science, engineering, technology, and art within our E-LKPD, students were provided with authentic, interdisciplinary problems that demanded application of reasoning rather than rote calculation—deepening literacy through context-rich scenarios.

Our evidence that medium- and low-achieving students gained equivalently (or slightly more) than high achievers reinforces the value of differentiation. This echoes findings by Adare et al. (2023) in Zambia, where classrooms with tailored resources and differentiated instruction showed significantly higher engagement and performance (Cohen's $d \approx 0.7$). Haelermans (2022) similarly underscores how grouping by learning strategies and varied learner pathways fosters motivation and metacognitive development. By intentionally integrating tiered tasks and scaffolded digital support, our E-LKPD allowed each learner to access content at their readiness level—effectively personalizing challenge and support.

E-LKPD's interactivity—embedded multimedia, branched tasks, and instant feedback—served as a critical enabler for both STEAM integration and differentiation. International reviews highlight the potential of technology to make STEAM learning more immersive and retention more durable (Delgado-Rodríguez et al., 2023). Our findings suggest that these affordances reduced cognitive overload (especially for low achievers), allowed for exploratory learning, and provided multiple representations, aligning with constructivist models of meaningful mathematics learning.

Constructivist Learning Theory advocates that learners build knowledge through active problem-solving in authentic contexts; our STEAM tasks exemplified this by embedding mathematics into real-world design challenges. Situated Cognition posits that learning is most effective when embedded in context-rich activity; by situating mathematics in interdisciplinary problems, students could transfer and apply reasoning skills more flexibly. Additionally, Differentiated Instruction theory (Tomlinson, 1999) argues for matching what students learn, how they learn, and how they show learning to their profiles. Our findings provide empirical support that technology-mediated STEAM activities can operationalize such tailoring effectively.

While our study focused on student outcomes, the successful design and classroom enactment of the E-LKPD depended heavily on teacher collaboration and readiness. Tang et al. (2025) report that teachers' intention to implement STEAM is influenced by perceived usefulness and availability of resources, and that boosting STEAM literacy among educators is key to implementation fidelity. Therefore, advancing such innovations likely requires parallel investments in teacher professional development and support structures to ensure sustainability and scalability.

Our study, though robust, is constrained by its sample size and setting—a single high school. Future research could examine long-term retention of mathematical literacy gains, differential impacts by domain (e.g., reasoning vs. modeling), and scalability across diverse educational contexts. Including rigorous control groups or quasi-experimental designs may further strengthen causal inferences.

Our research contributes to the field by demonstrating that a STEAM-based differentiated E-LKPD can meaningfully elevate mathematical literacy among diverse high-school learners. It confirms theoretical expectations from constructivist and DI frameworks, aligns with recent empirical findings on STEAM and digital differentiation, and highlights the critical role of teacher readiness and supportive infrastructure. Further research and sustained implementation efforts are essential to translate these design insights into broader educational impact.

The findings of this study revealed a significant improvement in students' mathematical literacy after the implementation of the STEAM-based differentiated E-LKPD. This aligns with the constructivist learning perspective, which emphasizes active knowledge construction through meaningful and contextualized experiences (Piaget, 1970; Vygotsky, 1978). The integration of STEAM components—science, technology, engineering, arts, and mathematics—provided authentic contexts for mathematical problem-solving, thereby enhancing students' ability to apply mathematics in real-life situations.

The differentiation embedded in the E-LKPD also reflects Tomlinson's theory of differentiated instruction (Tomlinson, 2014), which highlights the need to adapt tasks, content, and processes to students' readiness levels, interests, and learning profiles. This study confirmed that differentiated strategies allow for more equitable learning opportunities, supporting previous empirical findings that differentiation can significantly improve students' achievement and engagement (Santangelo & Tomlinson, 2019).

The results suggest several pedagogical implications. First, the integration of STEAM with differentiated digital worksheets (E-LKPD) offers a viable pathway to foster mathematical literacy in secondary education. Teachers can leverage this model to bridge the gap between abstract mathematical concepts and real-world applications. Second, the study demonstrates that differentiation is not only feasible in digital environments but also enhances inclusivity, addressing diverse learner needs (Deunk et al., 2018). Third, the positive outcomes underline the importance of combining innovative pedagogy with technology, supporting calls for 21st-century learning environments that prepare students for complex problem-solving (Honey et al., 2021).

Despite its promising results, this study has several limitations. The quasi-experimental design without random assignment may limit the generalizability of the findings. The sample size was restricted to one high school, which might not fully represent broader populations. Furthermore, the implementation occurred over a limited timeframe, which constrains the evaluation of long-term impacts. Finally, the study primarily focused on cognitive outcomes (mathematical literacy scores) without deeply examining affective or socio-emotional dimensions.

Future studies should expand the sample across multiple schools and regions to increase external validity. Longitudinal research is also recommended to capture sustained impacts of STEAM-based differentiated E-LKPD on mathematical literacy. Moreover, future investigations should consider incorporating mixed methods, including qualitative data on student motivation, engagement, and creativity, which may offer a more holistic understanding of the learning process. Lastly, comparative studies with other digital or non-digital interventions could provide deeper insights into the relative effectiveness of this approach.

CONCLUSION

This study demonstrated that the implementation of a STEAM-based differentiated E-LKPD significantly enhanced students' mathematical literacy. By integrating STEAM principles with differentiated instruction, the intervention provided meaningful, contextualized, and inclusive learning experiences that supported diverse learners in applying mathematics to real-world problems. The findings reinforce theoretical perspectives on constructivism and differentiation, highlighting the potential of technology-enhanced learning environments to improve both engagement and achievement.

While the study revealed promising results, limitations related to scope, duration, and generalizability suggest the need for broader and longer-term investigations. Nevertheless, the outcomes underscore the

importance of designing digital learning resources that are adaptive, innovative, and aligned with 21st-century skills. This research contributes to the growing body of evidence advocating for STEAM-based approaches and provides practical insights for educators aiming to cultivate mathematical literacy through differentiated digital tools.

REFERENCE

- Deunk, M. I., Smale-Jacobse, A. E., de Boer, H., Doolaard, S., & Bosker, R. J. (2018). Effective differentiation practices: A systematic review and meta-analysis of studies on the cognitive effects of differentiation in primary education. *Educational Research Review*, 24, 31–54.
- Haagen-Schützenhöfer, C., Obczovsky, M., & Kislinger, P. (2023). Design-based research—Tension between practical relevance and knowledge generation. *EURASIA Journal of Mathematics, Science and Technology Education*, 20(1), em2378.
- Honey, M., Pearson, G., & Schweingruber, H. (2021). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.
- Insorio, A. O. (2024). Addressing student diversity to improve mathematics achievement through differentiated instruction. *International Journal of Professional Development, Learners and Learning*, 6(1), ep2406.
- Nildasari, N., & Nur, R. (2024). The Effectiveness of Wizer.me in Developing Electronic Learning Materials: A Study with English Teacher. *JELITA*, 5(2), 501-515.
- Nurwijayanti, S., & Sulisworo, D. (2022). Development of E-LKPD based on PBL to improve students' mathematical communication skills. *AdMathEduSt*, 9(2), 41–51.
- OECD. (2023). *PISA 2022 Results Volume I & II: State of Learning and Equity in Education; Learning during – and from – Disruption*. OECD Publishing.
- Piaget, J. (1970). *Science of education and the psychology of the child*. Orion Press.
- Rahayu, S. T., et al. (2025). Development of an ethnomathematics-based E-LKPD on flat-sided solid geometry to enhance elementary students' critical thinking skills. *Al-Jabar: Jurnal Pendidikan Matematika*, 16(1), 292-303.
- Rahma, S., Ningsih, S., & Dewi, R. M. (2024). E-LKPD PBL in economics to train critical thinking skills. *Edukatif*, 6(2), 1675–1685.
- Sánchez Milara, I., & Cortés Orduña, M. (2024). *Possibilities and challenges of STEAM pedagogies*. Cornell University.
- Santangelo, T., & Tomlinson, C. A. (2019). Teacher educators' perceptions and use of differentiated instruction practices: An exploratory investigation. *Action in Teacher Education*, 41(3), 226–244.
- Singh, M., Azad, I., Qayyoom, M., A., Khan, T. (2024). A study on perceptions and practices of STEAM-based education with university students. *Social Sciences & Humanities Open*, Vol 10, 101162.
- Susanta, A., Susanto, E., Rusnilawati, Sumardi, H., & Ali, S. R. B. (2025). Literacy skills through the use of digital STEAM-inquiry learning modules: A comparative study of urban and rural

- elementary schools in Indonesia. *Eurasia Journal of Mathematics, Science and Technology Education*, 21(4), em2615.
- Syafrudin, Rayendra, Zen, Z., & Zuwirna. (2025). Development of E-LKPD Based on Technology Pedagogical and Content Knowledge (TPACK) in High School Mathematics Subjects. *Jurnal Penelitian Pendidikan IPA*, 11(7), 221–229.
- Tang, M., Wijaya, T.T., Li, X. et al. Exploring the determinants of mathematics teachers' willingness to implement STEAM education using structural equation modeling. *Sci Rep* 15, 6304 (2025).
- Tomlinson, C.A. (2014). *The Differentiated Classroom: Responding to the Needs of All Learners. 2nd Edition*, ASCD, Alexandria.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.
- Wu, X., Yang, Y., Zhou, X. et al. (2024). A meta-analysis of interdisciplinary teaching abilities among elementary and secondary school STEM teachers. *IJ STEM Ed* 11, 38.
- Zehui Yang & Yan-Yi Lee. (2025). Challenges and opportunities of design-based research in applied linguistics: Insights from a scoping review. *Research Methods in Applied Linguistics*, 4 (1), 100178.