Data Literacy and Logical Reasoning: A New Foundation for STEM Education in the Age of Information Abundance

Muhammad Hasbi [1*], Harling Danil[2], Sri Verlin[3], Hardi Yanti[4]
[1*,2,3,4]Universitas Islam As'adiyah Sengkang, Indonesia

Article Info
Article history:
Received Apr 03, 2026
Accepted May 09, 2026
Published Online Jul 09, 2026

Keywords:
Data Literacy
Logical Reasoning
STEM Education
Information Age
Islamic School

ABSTRACT

In the era of information abundance, students frequently encounter "cognitive disruptions" or logical fallacies when synthesizing scientific conclusions. This challenge is particularly pronounced within the Madrasah educational environment, where a critical need exists to bridge traditional verification values with contemporary data literacy. This study evaluates the effectiveness of synergizing data literacy and logical reasoning as a foundational framework for STEM education at Madrasah As'adiyah Pompanua, aiming to enhance students' cognitive capacity in formulating valid scientific arguments. Employing a quantitative quasi-experimental design, this research involved two student cohorts. Data were collected through assessments of data literacy and the Test of Logical Thinking (TOLT), then analyzed using descriptive statistics, ANCOVA, and Normalized Gain (N-Gain) analysis. The findings demonstrate that integrating data literacy and logical reasoning significantly improves STEM educational outcomes. The experimental group attained a mean score of 81.30, substantially outperforming the control group's 62.55. Data literacy was found to sharpen cognitive acuity by establishing an empirical foundation that minimizes logical gaps. The model's high efficacy is evidenced by an N-Gain value of 0.71, signifying a pedagogical shift from passive knowledge acquisition to critical analysis. This research contributes to the evolution of STEM models in Islamic educational settings by demonstrating that indigenous values, such as the principle of verification (tabayyun), serve as potent catalysts for adopting data literacy. Practically, this study provides a strategic framework for educators to implement evidence-based learning, ensuring students possess the essential analytical competencies required to navigate the complexities of the digital age.

Corresponding Author:
Muhammad Hasbi,
English Education, Faculty of Tarbiyah and Teacher Training,
Universitas Islam As'adiyah Sengkang,
Lapongkoda, Kec. Tempe, Kabupaten Wajo, Sulawesi Selatan, Indonesia
Email: muhammadhasbi@unisad.ac.id

How to cite: Hasbi, M., Danil, H., Verlin, S., & Yanti, H. (2026). Data Literacy and Logical Reasoning: A New Foundation for STEM Education in the Age of Information Abundance. *Jurnal Riset Dan Inovasi Pembelajaran*, *6*(2), 734–746. Retrieved from https://etdci.org/journal/jrip/article/view/5017

Data Literacy and Logical Reasoning: A New Foundation for STEM Education in the Age of Information Abundance

1. Introduction

The contemporary global landscape is currently defined by a phase of "infobesity," or an inevitable information explosion. Digitalization has fundamentally transformed the mechanisms through which humans produce, distribute, and consume data (Shafik, 2025). Every second, trillions of bytes of data are generated through multifaceted interactions, including social media engagement, IoT sensor deployment, and digital transactions (Kumar et al., 2024). However, this data proliferation does not inherently correlate with a proportionate increase in knowledge. On the contrary, the surge of post-truth narratives, disinformation, and misinformation poses profound threats to the cognitive fabric of modern society, rendering data literacy no longer merely an auxiliary skill, but an essential survival competency for the 21st century (Gündüzalp, 2021; Wolff et al., 2016).

STEM (Science, Technology, Engineering, and Mathematics) education has long been recognized as a primary catalyst for global innovation (Kennedy & Odell, 2023; Mudaly & Chirikure, 2023; Tytler, 2020). Nevertheless, the pedagogical requirements of STEM have shifted significantly. While historical models emphasized the mastery of technical content, contemporary challenges necessitate that students navigate vast oceans of data to construct valid scientific conclusions. Data literacy mandates the ability to interpret, manipulate, analyze, and reason through information. Without a robust foundation in data literacy, STEM instruction risks producing individuals capable of technical operation but ill-equipped to interpret the substance or reliability of their findings (Friedrich et al., 2024; Schreiter et al., 2024).

When addressed in isolation, data literacy often remains purely technical or procedural. To establish a more resilient educational foundation, it requires a substantive integration with logical reasoning (Biehler et al., 2017; Russo & Blikstein, 2025). Logical reasoning serves as the essential driving force behind rigorous data analysis. It functions as a critical cognitive filter, enabling learners to distinguish between mere correlation and actual causality, identify algorithmic biases, and construct coherent arguments grounded in empirical evidence (Bronkhorst et al., 2020).

In an educational context, the synergy between data literacy and logical reasoning facilitates what scholars describe as "new literacies" within STEM curricula (Dobryakova et al., 2023; Sheldon & Castek, 2023). Under this paradigm, students are moved beyond basic statistical calculation or graph generation toward critical inquiry, addressing fundamental questions such as: "Why does this data reflect this specific trend?", "Is this sample truly representative?", and "What logic underpins this prediction?" The historical lack of integration between technical processing skills and logical interpretation remains a critical vulnerability in conventional STEM education.

This challenge is particularly pertinent at Madrasah As'adiyah Pompanua, an institution characterized by its commitment to both Islamic intellectual traditions and scientific advancement. The institution faces a dual mandate: preserving spiritual identity and morality while cultivating graduates who are competitive in science and technology. Currently, the integration of STEM in such environments often encounters the misconception that scientific inquiry is distinct from character education or the formal logic traditionally emphasized in Islamic teachings.

However, Madrasah As'adiyah Pompanua possesses strategic potential for this integration. The Islamic intellectual tradition has historically prioritized logic (mantiq) and the pursuit of evidence-based truth. Introducing a STEM framework rooted in data literacy and logical reasoning at this institution represents a necessary deconstruction and reconstruction of current learning practices. This shift is vital to ensure that students transition from passive technology consumers to active contributors of data-driven solutions, all while remaining grounded in logical and ethical values. Initial observations suggest that despite increased access to digital facilities, data usage in science learning at the school remains limited to superficial administrative levels.

While numerous studies have explored STEM education broadly (Gui et al., 2023; Martín Páez et al., 2019; Ortiz-Revilla et al., 2022; Wang et al., 2022; Zhou et al., 2023), there remains a dearth of research examining the symbiotic interaction between data literacy and logical reasoning within secondary faith-based curricula. Existing literature frequently conflates data literacy with general ICT literacy (Alkan & Meinck, 2016; Martínez-Bravo et al., 2022; Tinmaz et al., 2022), whereas it is more accurately aligned with mathematics and science literacy, which demand sharp logical acuity (Friedrich et al., 2024; Schreiter et al., 2024). Furthermore, the emergence of cognitive "breaks" where students conduct experiments but fail to execute complex logical inferences remains a critical hurdle (Ruf et al., 2026; Tan et al., 2023).

This research offers originality by introducing an interdisciplinary "Foundational Synergy" model that fuses logical reasoning with data literacy. This framework is uniquely strengthened by a philosophical-religious contextualization, aligning modern STEM approaches with the pedagogical logic of Madrasah As'adiyah Pompanua. By doing so, the study provides a strategic framework for educators to implement evidence-based learning, ensuring that students develop the analytical competencies required to navigate the complexities of the digital age. Ultimately, this approach aims to transform STEM education from rote formula memorization into a meaningful discovery process, equipping graduates to compete at national and international levels without compromising their core identity.

2. Method

This study employed a quantitative approach utilizing a quasi-experimental, non-equivalent control group design. This design was selected because the administrative structure of the Madrasah classrooms at Madrasah As'adiyah Pompanua precluded random assignment of individual students. To evaluate the proposed model, subjects were divided into two intact groups: an experimental group, which received STEM instruction integrated with a synergistic model of data literacy and logical reasoning, and a control group, which engaged in conventional STEM learning. This structural arrangement allowed for an empirical assessment of the intervention's effectiveness while preserving the stability of the existing educational environment.

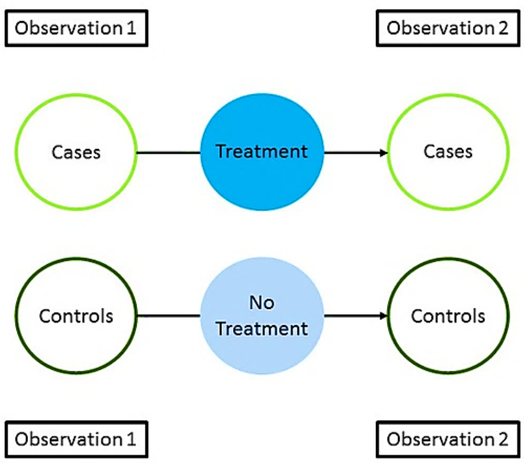

Figure 1. Non-equivalent Control Group Design

This study was conducted at Madrasah As'adiyah Pompanua, Bone Regency, during the odd semester of the 2025/2026 academic year, to investigate the integration of technology and data literacy within a faith-based educational context. The study population comprised all Grade 11 students (Phase F), with cluster random sampling employed to identify two classes Class XI-A and Class XI-B that demonstrated equivalent academic profiles based on prior scholastic records. Consequently, Class XI-A was designated as the experimental group, while Class XI-B served as the control group to facilitate a rigorous comparative analysis of the proposed learning model's efficacy.

The pedagogical intervention integrated data literacy and logical reasoning into STEM education through a four-stage framework derived from the data inquiry cycle. The process commenced with "Data Provocation," where students engaged with authentic, complex raw data pertinent to the Pompanua region. This was followed by "Logical Filtering," which required the application of deductive and inductive reasoning to assess information relevance, and "Modeling and Analysis," where students developed scientific or engineering solutions using digital tools. The cycle concluded with "Evidence-Based Argumentation," directing students to articulate findings that prioritized logical validity and accurate data interpretation.

Research variables were assessed using three validated and reliable instruments. The Logical Reasoning Test (LRT), adapted from the Test of Logical Thinking (TOLT), measured critical cognitive facets, including proportional reasoning, probability, correlation, and variable control. Concurrently, the Data Literacy Test (TLD) utilized a mixed format of multiple-choice and essay tasks to evaluate statistical interpretation skills and the ability to identify information bias. To supplement these quantitative measures, a STEM Activity Observation Sheet was employed to systematically monitor student engagement and classroom interaction levels throughout the intervention.

Data analysis followed a dual-path approach: descriptive statistics were first utilized to characterize the distribution of performance via means, standard deviations, and score ranges. Subsequently, inferential statistical analysis was performed, beginning with the Kolmogorov-Smirnov test for normality and Levene's test for homogeneity of variance. Hypothesis testing was executed using Analysis of Covariance (ANCOVA), which integrated pre-test scores as a covariate to adjust for initial group disparities and isolate the net effect of the intervention. Furthermore, Normalized Gain (N-Gain) scores were calculated to quantify the magnitude of cognitive improvement following the experimental treatment.

Table 1. Operational Matrix of Variables

Variables	Key Indicators	Assessment Techniques
Data Literacy	Source identification, trend analysis, data visualization, and information validity evaluation.	Performance and Portfolio Tests
Logical Reasoning	Systematic thinking, drawing conclusions (syllogisms), and identifying causal relationships.	Written Test (TOLT)
STEM Education	Integration of science and mathematics in technical problem-solving.	Project Sheets

3. Research Findings

Description of Initial Abilities (Pre-test)

Prior to the intervention, both the experimental and control groups underwent a baseline assessment to determine their initial proficiency in data literacy and logical reasoning. As summarized in Table 1, the pre-test results indicated that the mean scores for both cohorts fell within the "Low" to "Fair" range, demonstrating a relatively homogeneous distribution of academic capabilities and establishing a comparable starting point for the subsequent comparative analysis.

Table 1. Comparison of Pre-test Scores for the Experimental and Control Groups

Research Variables	Group	N	Mean	Standard Deviation	Category
Data Literacy	Experimental	32	52.45	7.82	Low
	Control	30	51.9	8.1	Low
Logical Reasoning	Experimental	32	47.6	9.15	Low
	Control	30	48.15	8.75	Low

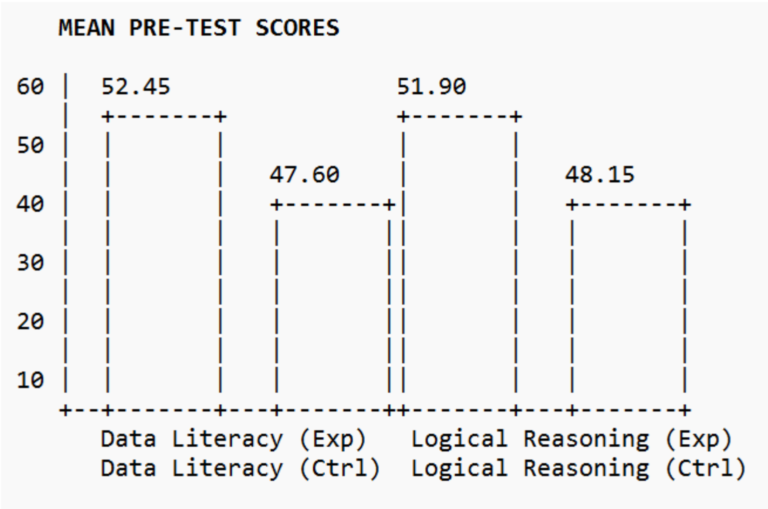

Figure 2. Pre-test Scores for the Experimental and Control Groups

The descriptive analysis confirms that the participants in both the experimental and control groups possessed equivalent baseline competencies prior to the implementation of the treatment. Regarding the data literacy variable, the experimental group obtained a mean score of 52.45 (SD = 7.82), whereas the control group attained a mean of 51.9 (SD = 8.1). A parallel trend was observed in logical reasoning aptitude, with the experimental group recording a mean of 47.6 (SD = 9.15) and the control group achieving 48.15 (SD = 8.75). These findings indicate that, across both variables and cohorts, baseline performance was categorized as low, with data distributions reflecting consistent homogeneity.

The marginal disparity in mean scores amounting to a negligible 0.55 for both research variables further corroborates the initial homogeneity of the sample. This equivalence in baseline characteristics provides a robust foundation for experimental design, as it effectively mitigates the potential for pre-existing inequality bias. Consequently, any statistically significant improvements observed in the post-test phase can be attributed primarily to the efficacy of the intervention rather than to exogenous variables related to the participants' initial academic aptitude.

Final Ability Analysis (Post-test)

Table 2 illustrates the comparative post-test results following the integration of data literacy within the STEM framework over one complete instructional cycle. The data analysis was conducted to rigorously evaluate the efficacy of the intervention and to quantify the extent to which the STEM-integrated approach enhances students' learning outcomes and data literacy competencies in comparison to conventional pedagogical methods employed in the control group.

Table 2. Comparison of Post-test Scores for the Experimental and Control Groups

Research Variables	Group	N	Mean	Standard Deviation	Category

Data Literacy	Experimental	32	84.75	5.12	Very High
	Control	30	67.4	6.85	Quite
Logical Reasoning	Experimental	32	81.3	6.4	High
	Control	30	62.55	7.9	Quite

The post-test analysis revealed a statistically significant disparity in performance between the experimental and control groups following the intervention. The experimental group attained a mean score of 84.75 in data literacy (categorized as 'Very High') and 81.3 in logical reasoning (categorized as 'High'). These outcomes notably outperformed the control group, which remained within the 'Fair' category across both metrics, with mean scores of 67.4 and 62.55, respectively.

The efficacy of the pedagogical intervention is evidenced by the substantial mean differences of 17.35 points in data literacy and 18.75 points in logical reasoning. Furthermore, the experimental group exhibited superior performance stability, characterized by lower standard deviations compared to the control group. These findings suggest that the intervention not only enhanced students' competencies more effectively but also facilitated a more uniform distribution of learning gains, thereby elevating student proficiency to a significantly higher threshold than that achieved through conventional instructional methods.

Hypothesis Testing (ANCOVA)

To statistically validate the observed performance disparities between the groups while simultaneously controlling for the influence of baseline competencies, an Analysis of Covariance (ANCOVA) was performed; the results are delineated in Table 3 under the 'Tests of Between-Subjects Effects.' The application of the ANCOVA procedure was essential to isolate the treatment effect, ensuring that the post-test score differentials between the experimental and control groups could be attributed specifically to the pedagogical intervention, thereby effectively mitigating potential biases stemming from pre-existing variations in students' initial abilities.

Table 3. ANCOVA Test Results (Tests of Between-Subjects Effects)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8420.45	2	4210.225	112.45	0.000
Pre-test (Covariate)	1250.11	1	1250.11	33.38	0.000
Group (Treatment)	7150.34	1	7150.34	190.92	0.000
Error	2210.5	59	37.466		
Total	245000	62			

This analysis was performed to evaluate the treatment effect on the dependent variables by utilizing pre-test scores as a covariate, thereby ensuring the robustness and accuracy of the research findings. The ANCOVA results for the 'group' factor yielded a significance value of $p < 0.001$ ($p < 0.05$), demonstrating a statistically significant divergence in data literacy and logical reasoning proficiency between the experimental and control groups, even after controlling for baseline performance. Furthermore, the pre-test covariate yielded an F-statistic of 33.38 ($p < 0.001$), confirming that initial student competencies exerted a significant influence on post-test achievement, which justifies the employment of the ANCOVA model to isolate and refine the treatment effect.

The integrity of the research model is further substantiated by the Corrected Model F-statistic of 112.45 ($p < 0.001$), indicating that the pedagogical intervention and baseline abilities, in tandem, serve as robust predictors of the variance observed in student learning outcomes. From a practical standpoint, the substantial disparity between the Mean Square of the treatment group (7150.34) and the Mean Square Error (37.466) underscores the dominant effect size of the intervention. These findings provide compelling empirical evidence that the integration of data literacy and logical reasoning within a STEM framework is significantly more efficacious than conventional instructional methodologies in advancing students' academic competencies.

Effectiveness Test (N-Gain)

To quantify the magnitude of performance improvement before and after the intervention, an N-Gain (Normalized Gain) score analysis was conducted; the findings are detailed in Table 4. This metric serves as an objective gauge to assess the effectiveness of the proposed learning model in enhancing students' data literacy and logical reasoning proficiency. By utilizing N-Gain scores, this study provides a comprehensive evaluation of the substantial growth in academic competencies within the experimental cohort, facilitating a rigorous comparative analysis against the control group.

Table 4. N-Gain Score Analysis Results

Group	Average N-Gain	Percentage (%)	Effectiveness Criteria
Experiment	0.71	71%	High / Effective
Control	0.32	32%	Moderate / Less Effective

The N-Gain analysis was performed to quantify the pedagogical effectiveness of the intervention by calculating the normalized gain between pre-test and post-test scores. The experimental group yielded a mean N-Gain score of 0.71 (71%), which is classified under the 'High' effectiveness criterion. This result suggests that the intervention successfully facilitated substantial advancements in both data literacy and logical reasoning competencies.

In contrast, the control group attained a mean N-Gain of 0.32 (32%), placing it within the 'Moderate' or 'Less Effective' category. The 39% performance disparity between the two groups provides robust evidence that the proposed instructional model is significantly more effective than conventional pedagogical approaches. Collectively, these findings demonstrate that the intervention serves as a powerful catalyst for enhancing student proficiency, surpassing the academic gains typically achieved through traditional teaching methodologies.

Observation Results

Field observations conducted at Madrasah As'adiyah Pompanua indicate that the implementation of the proposed learning model significantly enhanced students' cognitive and analytical capabilities. Within the STEM framework, participants demonstrated high proficiency in synthesizing statistical data such as fluctuations in local commodity prices—with mathematical principles through structured logical reasoning. These outcomes confirm that the pedagogical approach effectively bridged theoretical concepts with real-world contexts relevant to the students' immediate environment.

Beyond cognitive gains, substantial development was observed in students' scientific communication skills, particularly in the construction of evidence-based arguments. The problem-solving process now reflects a rigorous reliance on independently generated data visualizations, leading to conclusions that are empirically valid and substantiated rather than speculative. A comprehensive overview of student performance progress throughout the intervention is delineated in Table 5, which synthesizes the observational results regarding the implementation of the learning model.

Table 5. Observation Results of the Implementation of the Learning Model

Observation Aspects	Description of Observation Findings
Cognitive and Analytical Abilities	There was a significant improvement in students' ability to relate statistical data (such as local commodity price fluctuations) to STEM mathematics principles.
Logical Reasoning	Students were able to demonstrate logical and structured thought processes in solving given problems.
Scientific	There was substantial improvement in students' skills in presenting

Observation Aspects	Description of Observation Findings
Communication	arguments supported by strong evidence.
Conclusion Drawing Methods	Students progressed from simply guessing answers to being able to consistently refer to independently compiled data visualizations as a basis for valid decision-making.

4. Discussion

Baseline analysis revealed that students at Madrasah As'adiyah Pompanua possessed homogeneous, albeit low, initial competencies in data literacy and logical reasoning. The marginal mean disparity (0.55) between groups confirms the absence of pre-existing competency bias, a methodological requisite in experimental research to ensure that post-intervention gains are attributable exclusively to the treatment rather than extraneous maturational or historical variables (Peteranderl et al., 2023).

Following the intervention, the experimental group exhibited substantial progress, achieving "Very High" and "High" proficiency levels in data literacy (84.75) and logical reasoning (81.3), respectively. These outcomes corroborate constructivist learning theory, which posits that pedagogical effectiveness is contingent upon active student engagement in information processing (Arega & Hunde, 2025; Zajda, 2021). Within the STEM framework, data literacy functions as a cognitive scaffold, enabling students to synthesize complex information into structured knowledge architectures. Furthermore, the integration of real-world contexts, such as local commodity price fluctuations, acts as a primary catalyst for enhanced motivation and cognitive retention (Rashed et al., 2025). This aligns with established literature emphasizing that authentic, problem-based STEM education facilitates superior knowledge transfer compared to abstract instructional approaches (Liu, 2025; Smith et al., 2022; Su, 2024).

The intervention further catalyzed a transition in learning culture from speculative reasoning to evidence-based argumentation. The students' improved capacity to derive valid conclusions through independent data visualization reflects the development of higher-order thinking skills, particularly the ability to evaluate, analyze, and synthesize information (Cui et al., 2023; Filderman et al., 2022). Statistically, the ANCOVA results ($p < 0.001$) and the Corrected Model F-statistic (112.45) confirm that the STEM intervention and baseline abilities are robust predictors of learning outcomes. These results are consistent with cognitive load theory; an integrated STEM structure optimizes working memory by grouping logically interrelated concepts (Maj, 2020; Sultanova, 2025).

The substantial disparity between the treatment Mean Square (7150.34) and the Mean Square Error (37.46) underscores the dominant effect size of the intervention. This suggests that data literacy serves as a reinforcing instrument that stabilizes logical reasoning (Xu et al., 2024), effectively reducing cognitive barriers during the resolution of complex STEM problems (Caton et al., 2022; Xu et al., 2025). Finally, the N-Gain analysis (0.71 vs. 0.32) confirms that the proposed model is significantly more effective than conventional methodologies, fostering not only cognitive gains but also analytical agility and scientific communication proficiency (Bou Saad et al., 2025; Govender, 2025).

This study contributes to pedagogical development at the secondary education level by demonstrating the synergy between data literacy and logical reasoning within a STEM framework. The findings suggest that the integration of realistic, contextual data such as local economic indicator effectively bridges theoretical mathematics with real-world phenomena. By prioritizing evidence-based argumentation, this model transforms the learning process, transitioning students from speculative decision-making to scientifically valid conclusions. Ultimately, the high N-Gain efficacy (0.71) validates this model as a strategic framework for educators aiming to significantly enhance students' cognitive and analytical competencies in an increasingly data-driven global landscape.

5. Conclusion

The integration of data literacy and logical reasoning within a STEM framework has demonstrated a transformative impact on instructional quality at Madrasah As'adiyah Pompanua. Empirical evidence from the experimental cohort, which attained a mean score of 81.30 compared to 62.55 in the control group, underscores the efficacy of this pedagogical synergy. Proficiency in data literacy enhances cognitive capacity by establishing an empirical foundation that mitigates logical fallacies, thereby empowering students to formulate scientifically rigorous and critical conclusions. Furthermore, the substantial N-Gain score of 0.71 suggests that the contextualization of learning specifically by embedding values of verification and accuracy (tabayyun) serves as a robust catalyst for cultivating data literacy within information-rich learning environments.

In light of these findings, the authors propose a strategic framework comprising three core recommendations: first, educators in STEM disciplines at Madrasah As'adiyah Pompanua are encouraged to shift pedagogical orientations from rote formula memorization toward data-driven inquiry and logical reasoning, with an emphasis on visual information interpretation; second, administrators should formulate policies to institutionalize data literacy as a cross-disciplinary competency, supported by enhanced digital infrastructure and sustained professional development in data analysis tools; and finally, future research should longitudinalize study scopes to primary education levels to track cognitive development trajectories while exploring the integration of emerging Technologies such as Artificial Intelligence (AI) and Big Data Analytics to further strengthen data literacy synergies within faith-based educational contexts.

6. Conflict of Interest

The authors declare no conflict of interest.

7. Author Contributions

M.H. conceptualized the research idea presented, collected the data, and wrote. The other three authors (H.D., S.R., and H) actively contributed to the development of the theory, methodology, data organization and analysis, discussion of the results, and approval of the final version of the work. All authors confirm that they have read and approved the final version of this manuscript. The percentage contributions for the conceptualization, drafting, and revision of this paper are as follows: M.H.: 40%, H.D.: 20%, S.R.: 20%, and H.: 20%.

8. Data Availability Statement

The authors state that the data supporting the findings of this study will be made available by the corresponding author, [M.H], upon reasonable request.

REFERENCES

Alkan, M., & Meinck, S. (2016). The relationship between students' use of ICT for social communication and their computer and information literacy. *Large-Scale Assessments in Education*, *4*(1), 15. https://doi.org/10.1186/s40536-016-0029-z

Arega, N. T., & Hunde, T. S. (2025). Constructivist instructional approaches: A systematic review of evaluation-based evidence for effectiveness. *Review of Education*, *13*(1), e70040. https://doi.org/10.1002/rev3.70040

Biehler, R., Frischemeier, D., Reading, C., & Shaughnessy, J. M. (2017). Reasoning about data. *International handbook of research in statistics education*, 139-192. https://doi.org/10.1007/978-3-319-66195-7_5

Bou Saad, R., Garcia, A. L., & Garcia, J. M. C. (2025). Mapping constructivist active learning for STEM: Toward sustainable education. *Sustainability*, *17*(13), 6225.

https://doi.org/10.3390/su17136225

Bronkhorst, H., Roorda, G., Suhre, C., & Goedhart, M. (2020). Logical reasoning in formal and everyday reasoning tasks. *International Journal of Science and Mathematics Education*, *18*(8), 1673-1694. https://doi.org/10.1007/s10763-019-10039-8

Caton, A., Bradshaw-Ward, D., Kinshuk, K., & Savenye, W. (2022). Future directions for digital literacy fluency using cognitive flexibility research: A review of selected digital literacy paradigms and theoretical frameworks. *Journal of Learning for Development*, *9*(3), 381-393. https://doi.org/10.56059/jl4d.v9i3.818

Cui, Y., Chen, F., Lutsyk, A., Leighton, J. P., & Cutumisu, M. (2023). Data literacy assessments: a systematic literature review. *Assessment in education: Principles, policy & Practice*, *30*(1), 76-96. https://doi.org/10.1080/0969594X.2023.2182737

Dobryakova, M., Froumin, I., Moss, G., Seel, N., Barannikov, K., & Remorenko, I. (2023). A framework of key competences and new literacies. In *Key competences and new literacies: From slogans to school reality* (pp. 27-56). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-23281-7_3

Filderman, M. J., Toste, J. R., Didion, L., & Peng, P. (2022). Data literacy training for K–12 teachers: A meta-analysis of the effects on teacher outcomes. *Remedial and Special Education*, *43*(5), 328-343. https://doi.org/10.1177/07419325211054208

Friedrich, A., Schreiter, S., Vogel, M., Becker-Genschow, S., Brünken, R., Kuhn, J., ... & Malone, S. (2024). What shapes statistical and data literacy research in K-12 STEM education? A systematic review of metrics and instructional strategies. *International Journal of STEM Education*, *11*(1), 58. https://doi.org/10.1186/s40594-024-00517-z

Govender, I. (2025). Digital literacy and STEM skills–What is the connection? A systematic review. *Technology, Knowledge and Learning*, 1-22. https://doi.org/10.1007/s10758-025-09879-x

Gui, Y., Cai, Z., Yang, Y., Kong, L., Fan, X., & Tai, R. H. (2023). Effectiveness of digital educational game and game design in STEM learning: a meta-analytic review. *International Journal of STEM Education*, *10*(1), 36. https://doi.org/10.1186/s40594-023-00424-9

Gündüzalp, S. (2021). 21st century skills for sustainable education: Prediction level of teachers' information literacy skills on their digital literacy skills. *Discourse and Communication for Sustainable Education*, *12*(1), 85-101. https://doi.org/10.2478/dcse-2021-0007

Kennedy, T. J., & Odell, M. R. (2023). STEM Education as a Meta-discipline. In *Contemporary issues in science and technology education* (pp. 37-51). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-24259-5_4

Kumar, S., Verma, A. K., & Mirza, A. (2024). Digitalisation, artificial intelligence, IoT, and industry 4.0 and digital society. In *Digital transformation, artificial intelligence and society: opportunities and challenges* (pp. 35-57). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-97-5656-8_3

Liu, Z. (2025). Study on design and practice of PBL teaching model based on STEM education concept. *Scientific Reports*, *15*(1), 32876. https://doi.org/10.1038/s41598-025-18485-x

Maj, S. P. (2020). Cognitive load optimization–a statistical evaluation for three STEM disciplines. In *2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)* (pp. 414-421). IEEE. https://doi.org/10.1109/TALE48869.2020.9368430

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, *103*(4), 799-822. https://doi.org/10.1002/sce.21522

Martínez-Bravo, M. C., Sádaba Chalezquer, C., & Serrano-Puche, J. (2022). Dimensions of digital literacy in the 21st century competency frameworks. *Sustainability*, *14*(3), 1867.

https://doi.org/10.3390/su14031867

Mudaly, R., & Chirikure, T. (2023). STEM education in the Global North and Global South: Competition, conformity, and convenient collaborations. *Frontiers in Education* (Vol. 8, p. 1144399). Frontiers Media SA. https://doi.org/10.3389/feduc.2023.1144399

Ortiz-Revilla, J., Greca, I. M., & Arriassecq, I. (2022). A theoretical framework for integrated STEM education. *Science & Education*, *31*(2), 383-404. https://doi.org/10.1007/s11191-021-00242-x

Peteranderl, S., Edelsbrunner, P. A., Deiglmayr, A., Schumacher, R., & Stern, E. (2023). What skills related to the control-of-variables strategy need to be taught, and who gains most? Differential effects of a training intervention. *Journal of Educational Psychology*, *115*(6), 813. https://doi.org/10.1037/edu0000799

Rashed, R. Q. G., Abubakar, A. A., Madani, O., & Al-Mamary, Y. H. (2025). Enhancing student engagement and motivation for sustainable education: The role of internship and institutional support. *Sustainability*, *17*(12), 5291. https://doi.org/10.3390/su17125291

Russo, R., & Blikstein, P. (2025). Data Literacy Beyond Logic: Entanglements of Logical Reasoning and Emotion in a Data Science Camp. In *Proceedings of the 19th International Conference of the Learning Sciences-ICLS 2025, pp. 808-816*. International Society of the Learning Sciences. https://doi.org/10.22318/icls2025.973215

Ruf, V., Thüs, D., Malone, S., Küchemann, S., Becker-Genschow, S., Vogel, M., ... & Kuhn, J. (2026). A Systematic Review of Empirical Research on Graphing Numerical Data in K–12 STEM Education: V. Ruf et al. *International Journal of Science and Mathematics Education*, *24*(3), 28. https://doi.org/10.1007/s10763-026-10653-3

Schreiter, S., Friedrich, A., Fuhr, H., Malone, S., Brünken, R., Kuhn, J., & Vogel, M. (2024). Teaching for statistical and data literacy in K-12 STEM education: a systematic review on teacher variables, teacher education, and impacts on classroom practice. *ZDM–mathematics education*, *56*(1), 31-45. https://doi.org/10.1007/s11858-023-01531-1

Shafik, W. (2025). The Darkside of Artificial Intelligence and the Metaverse in Scientific Research and Publishing: Navigating the Academic Standards in the Digital Era. In *Navigating AI and the Metaverse in Scientific Research* (pp. 275-304). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-0340-6.ch014

Sheldon, L., & Castek, J. M. (2023). New literacies: Expanding the conversation to include data literacies. In *Handbook of educational psychology* (pp. 579-602). Routledge. https://doi.org/10.4324/9780429433726-30

Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., ... & Smith, T. (2022). Principles of problem-based learning (PBL) in STEM education: Using expert wisdom and research to frame educational practice. *Education Sciences*, *12*(10), 728. https://doi.org/10.3390/educsci12100728

Su, K. D. (2024). The challenge and opportunities of STEM learning efficacy for living technology through a transdisciplinary problem-based learning activity. *Journal of Science Education and Technology*, *33*(4), 429-443. https://doi.org/10.1007/s10956-024-10094-z

Sultanova, G. (2025). Assessment tasks in STEM education: integrating Bloom's Revised Taxonomy and Cognitive Load Theory. *Research in Science & Technological Education*, 1-19. https://doi.org/10.1080/02635143.2025.2586564

Tan, A. L., Ong, Y. S., Ng, Y. S., & Tan, J. H. J. (2023). STEM problem solving: Inquiry, concepts, and reasoning. *Science & Education*, *32*(2), 381-397. https://doi.org/10.1007/s11191-021-00310-2

Tinmaz, H., Lee, Y. T., Fanea-Ivanovici, M., & Baber, H. (2022). A systematic review on digital literacy. *Smart Learning Environments*, *9*(1), 21. https://doi.org/10.1186/s40561-022-

00204-y
Tytler, R. (2020). STEM education for the twenty-first century. *Integrated approaches to STEM education: An international perspective*, 21-43. https://doi.org/10.1007/978-3-030-52229-2_3
Wang, C., Shen, J., & Chao, J. (2022). Integrating computational thinking in STEM education: A literature review. *International Journal of Science and Mathematics Education*, *20*(8), 1949-1972. https://doi.org/10.1007/s10763-021-10227-5
Wolff, A., Gooch, D., Montaner, J. J. C., Rashid, U., & Kortuem, G. (2016). Creating an understanding of data literacy for a data-driven society. *The Journal of Community Informatics*, *12*(3). https://doi.org/10.15353/joci.v12i3.3275
Xu, L., Ng, D. T. K., Lee, C. S. Y., Peng, P., & Chu, S. K. W. (2025). A systematic review of digital literacy in lifelong learning for older adults: challenges, strategies, and learning outcomes. *Educational technology research and development*, 1-48. https://doi.org/10.1007/s11423-025-10530-w
Xu, L., Zou, X., & Hou, Y. (2024). Effects of feedback visualisation of peer-assessment on pre-service teachers' data literacy, learning motivation, and cognitive load. *Journal of Computer Assisted Learning*, *40*(4), 1447-1462. https://doi.org/10.1111/jcal.12955
Zajda, J. (2021). Constructivist learning theory and creating effective learning environments. In *Globalisation and education reforms: Creating effective learning environments* (pp. 35-50). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-71575-5_3
Zhou, X., Shu, L., Xu, Z., & Padrón, Y. (2023). The effect of professional development on in-service STEM teachers' self-efficacy: A meta-analysis of experimental studies. *International Journal of STEM Education*, *10*(1), 37. https://doi.org/10.1186/s40594-023-00422-x

Author Biographies

	**Muhammad Hasbi,** is a lecturer and researcher in the English Language Education Study Program, Faculty of Tarbiyah and Teacher Training, As'adiyah Islamic University Sengkang, South Sulawesi, Indonesia. His research interests are Mathematics Education, Education, and Instruction. Affiliation: As'adiyah Islamic University of Sengkang, Phone: +6285253407367 Email: muhammadhasbi@unisad.ac.id
	**Harling Danil,** is a lecturer and researcher in the Islamic education Study Program, Faculty of Tarbiyah and Teacher Training, As'adiyah Islamic University Sengkang, South Sulawesi, Indonesia. His research interests are Islamic education. Affiliation: As'adiyah Islamic University of Sengkang, Phone: +6282333801704 Email: harlingdanil@unisad.ac.id
	**Sri Verlin,** is a lecturer and researcher in the Islamic Family Law Study Program, Faculty of Sharia and Law, As'adiyah Islamic University Sengkang, South Sulawesi, Indonesia. His research interests are Indonesian Language. Affiliation: As'adiyah Islamic University of Sengkang, Phone: +6285345653032 Email: sriverlin@unisad.ac.id

Hardi Yanti, is a lecturer and researcher in the Islamic education Study Program, Faculty of Tarbiyah and Teacher Training, As'adiyah Islamic University Sengkang, South Sulawesi, Indonesia. His research interests are Islamic education and Public health. Affiliation: As'adiyah Islamic University of Sengkang, Phone: +6282328001478
Email: hardiyanti@unisad.ac.id