Department of Digital Business
Journal of Artificial Intelligence and Digital Business (RIGGS)
Homepage: https://journal.ilmudata.co.id/index.php/RIGGS
Vol. 4 No. 4 (2025) pp: 4197-4205
P-ISSN: 2963-9298, e-ISSN: 2963-914X

The Impact of ICT-Integrated Learning on High School Students' Achievement in Mathematics: A Data-Driven Analysis

Nisa Miftachurohmah[1], Nasruddin[2], Markus Palobo[3]
[1]Program Studi Ilmu Komputer, FTI, Universitas Sembilanbelas November Kolaka, Kolaka, Indonesia
[2]Program Studi Pendidikan Matematika, FKIP, Universitas Sembilanbelas November Kolaka, Kolaka, Indonesia
[3]Program Studi Pendidikan Matematika, FKIP, Universitas Musamus, Merauke, Indonesia
nisa.informatics@gmail.com

Abstract

This study investigates the impact of Information and Communication Technology (ICT)-integrated learning on high school students' mathematics achievement through a comprehensive, data-driven quantitative approach. Utilizing a correlational research design, the study involved a sample of 230 students drawn from three public high schools in Southeast Sulawesi, Indonesia. Data were obtained from two primary sources: a validated questionnaire assessing the extent and quality of ICT usage in mathematics classrooms, and students' semester examination scores, which served as indicators of academic achievement. Descriptive statistical analysis was used to outline general patterns of ICT implementation, followed by Pearson correlation and multiple regression analyses to explore and quantify the relationship between ICT integration and student performance in mathematics. The findings demonstrate a significant positive correlation between ICT-integrated learning and students' academic outcomes ($r = 0.48, p < 0.01$). Regression results further reveal that ICT usage accounts for approximately 23% of the variance in mathematics achievement, indicating a substantial contribution of technology-enhanced learning to students' performance. These results suggest that effective incorporation of ICT tools—such as GeoGebra, Desmos, and various online learning platforms—can strengthen students' conceptual understanding, promote deeper engagement, and facilitate more interactive learning experiences. The study underscores the importance of enhancing teachers' digital pedagogical competencies and encourages the adoption of ICT-based instructional strategies that support active, interactive, and personalized learning within mathematics education.

Keywords*: Academic Achievement; Data-Driven Analysis; Ict Integration; Mathematics Education; Secondary School Students*

1. Introduction

Over the past two decades, Information and Communication Technology (ICT) has become a transformative force in mathematics education, shifting instruction from teacher-centered to interactive and student-centered learning [11]. Mathematics—often perceived as abstract and complex—requires both conceptual understanding and procedural fluency. Traditional pedagogies relying on direct instruction frequently fail to promote deep reasoning [2]. Hence, integrating ICT has become essential to overcome learning barriers and enhance achievement. In Indonesia, the Ministry of Education and Culture mandates ICT use to promote 21st-century skills: critical thinking, creativity, communication, and collaboration [8]. Yet, implementation remains uneven. Only a fraction of teachers use digital tools such as GeoGebra or Desmos to foster conceptual learning [20]. Limited access to technology and unequal digital competence lead to inconsistent results, signaling the need for empirical research linking ICT use to measurable learning outcomes.

ICT tools facilitate visualization and interactivity essential to mathematics learning. GeoGebra enables exploration of geometric relations, while Desmos helps students grasp algebraic functions dynamically [5]. Through manipulation and feedback, learners engage in discovery-based learning that builds motivation and engagement [28]. Moreover, ICT supports differentiated instruction tailored to diverse learning styles [24]. Still, effectiveness depends not merely on access but on purposeful pedagogical integration [9]. When used superficially, technology yields limited gains [25]; intentional design promoting active learning and collaboration is crucial [16].

Empirical studies in advanced education systems show a positive relationship between ICT and achievement. Cheung and Slavin [2] synthesized 74 studies involving 56,886 students, revealing significant improvement in mathematics outcomes—particularly when ICT supported individualized learning. Li and Ma [11] confirmed similar benefits for both procedural fluency and conceptual understanding. However, such evidence largely arises from Western contexts. Developing nations like Indonesia, where digital infrastructure and teacher readiness vary widely, need localized validation. Indonesian research provides emerging insights. Rahmawati [20] found that GeoGebra-based instruction moderately improved geometry learning. Santoso and Malik [23] reported that pandemic-era online platforms enhanced digital literacy but produced mixed academic effects. Complementary evidence from Miftachurohmah et al. [13] also shows that the Creative Problem Solving (CPS) model integrated with ICT significantly improved students' mathematics performance by combining digital interactivity with structured reasoning activities. These studies indicate ICT's potential but also its dependency on instructional quality and student engagement.

Pedagogically, ICT integration aligns with constructivist learning theory, where learners construct knowledge through exploration and reflection [18], [26]. ICT environments scaffold complex mathematical ideas via visualization and real-time feedback, strengthening metacognitive regulation [15]. However, despite increased motivation and positive attitudes, few studies directly connect ICT use to objective measures such as exam scores, leaving a research gap [1]. This study fills that gap through a data-driven approach combining validated ICT-usage instruments and real achievement data, enabling objective assessment. The design aligns with learning analytics and data-informed pedagogy trends [6]. Focused on Southeast Sulawesi, Indonesia, it contextualizes how ICT relates to mathematics performance amid infrastructural and pedagogical constraints. Its novelty lies in (1) empirical rather than perception-based data, (2) focus on a developing-country setting, and (3) quantitative modeling through correlation and regression analyses.

Extensive literature supports ICT's pedagogical value. Cheung and Slavin [2] showed small-to-moderate positive effects when technology promoted active problem-solving rather than passive delivery. Li and Ma [11] highlighted how interactive tools fostered understanding of complex mathematical concepts. Research by Tzafilkou et al. [24] and Yilmaz and Bayraktar [28] further found that interactivity and feedback enhance self-regulation and attitudes, reducing math anxiety. Nonetheless, limited teacher preparation in Indonesia constrains these benefits [10]. Only 38% of high-school math teachers routinely use digital simulations [19]. Across Southeast Asia, outcomes also vary. In Vietnam, Nguyen and Ha [17] observed improved geometry comprehension through visualization tools, whereas in Malaysia, Ismail et al. [29] found no significant exam-score changes when student support was inadequate. These mixed findings underline the importance of contextual studies like this one to capture local dynamics.

Emerging methodologies such as Learning Analytics (LA) and Educational Data Mining (EDM) now allow researchers to link ICT engagement patterns with performance [6], [21]. In Indonesia, such data-driven methods remain underused. As Salim [22] notes, over 70% of students struggle to contextualize abstract math problems under conventional teaching. ICT's visualization potential could mitigate this—but only if empirically substantiated. The study's theoretical foundation draws from constructivism [18], socio-cultural theory [26], and the TPACK framework [14], which posits that effective technology-based teaching requires a synthesis of technological, pedagogical, and content knowledge. ICT, as a "mindtool" [7], extends learners' cognitive capacity to represent and manipulate information meaningfully. Teachers adept at integrating these domains can foster higher-order mathematical reasoning.

Post-pandemic digital transformation intensifies the urgency of this research. Although ICT adoption expanded globally, inequities in access and teacher readiness persist [25]. Empirical evaluation is necessary to prevent superficial adoption that yields minimal learning impact [10]. Moreover, mathematics forms the foundation of STEM disciplines vital for national development. Strengthening mathematical achievement through ICT supports essential 21st-century analytical skills [27]. As Miftachurohmah et al. [12] demonstrated in ICT-based modeling for agricultural risk analysis, integrating digital tools with analytical reasoning enhances problem-solving accuracy—a principle equally applicable to mathematics education.

Situated at the intersection of educational technology, mathematics, and data analytics, this research aims to: (1) describe ICT-use patterns among high-school students, (2) analyze its correlation with mathematics achievement, and (3) determine ICT's predictive contribution to score variation. The outcomes are expected to enrich theory, demonstrate quantitative assessment methods, and guide teachers and policymakers in fostering equitable, data-driven, and technology-enhanced mathematics education.

DOI: https://doi.org/10.31004/riggs.v4i4.4039

2. Research Methods

Figure 1 presents the flowchart illustrating the sequence of procedures adopted in this study. The research utilized a quantitative correlational design to examine the relationship between the integration of Information and Communication Technology (ICT) in mathematics learning and students' academic achievement. The correlational approach was selected because it enables identification of the degree and direction of association between measurable variables without manipulating the learning environment [4]. The central purpose was to determine whether students who engage more intensively with ICT-based learning activities achieve higher mathematics scores compared to those with less engagement.

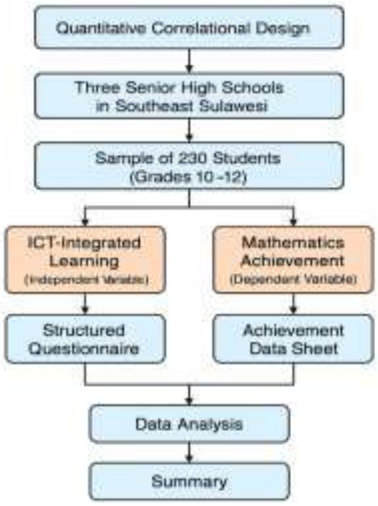

Figure 1. Research Method

The study was conducted at three public senior high schools in Southeast Sulawesi, Indonesia, purposively selected based on their active participation in digital learning initiatives and accessibility to ICT facilities. These schools implemented the standardized curriculum aligned with the Merdeka Belajar framework [8]. The sample consisted of 230 students selected, in Kolaka Southeast Sulawesi, using stratified random sampling. ICT-integrated learning was conceptualized across three dimensions—frequency, purpose, and perceived usefulness—drawing from validated instruments used in prior studies [2], [9], [28]. Mathematics achievement was measured through official semester examination scores.

The population comprised approximately 870 students in grades 10–12. Using the Slovin formula with a 5% margin of error, a representative sample of 230 students was obtained. The stratified random sampling technique ensured proportional representation from each grade level and gender group, thereby reflecting variations in ICT exposure and mathematical achievement across subgroups. Two key variables were measured: (1) ICT-Integrated Learning (Independent Variable) – defined as the extent to which students use digital tools, platforms, and resources in learning mathematics both inside and outside the classroom. This includes applications such as GeoGebra and Desmos [5], online assessments like Quizizz and Google Forms, and learning management systems such as Google Classroom and Moodle. ICT use was analyzed across three dimensions: frequency, purpose (practice, exploration, visualization, assessment), and perceived usefulness in supporting mathematical understanding; (2) Mathematics Achievement (Dependent Variable) – operationalized as the students' final semester examination score (scale 0–100), obtained from official school records. These standardized scores reflect objective performance evaluated by mathematics teachers under uniform criteria, strengthening data validity; (3) The instruments consisted of two components. The first was a structured questionnaire measuring ICT usage, comprising 15 items adapted from prior validated instruments [2], [28], [9]. Items were rated on a five-point Likert scale ranging from 1 (never) to 5 (very frequently). Examples included: "I use digital platforms to practice solving mathematical problems" and "I use visualization software such as GeoGebra to understand geometric concepts." Content validation was conducted by three senior mathematics education lecturers, followed by a pilot test involving 30 students from another school. The pilot produced a Cronbach's alpha of 0.89, indicating strong internal consistency.

DOI: https://doi.org/10.31004/riggs.v4i4.4039

The second instrument was an achievement data sheet, documenting students' mathematics examination scores obtained from official records with administrative permission. Data were anonymized to protect confidentiality, enhancing the objectivity and ethical integrity of the study. The data collection procedure consisted of three phases: (1) obtaining ethical clearance and official permission from the participating schools and local authorities; (2) administering the ICT usage questionnaire to students during class sessions under researcher supervision; and (3) collecting students' mathematics scores and matching them with questionnaire responses using anonymized codes. All participation was voluntary, with informed consent obtained from students and parental consent for those under 18.

Following data collection, the dataset underwent screening and cleaning. Responses were checked for completeness, with missing data (<5%) replaced using mean imputation, and outliers ($|z| > 3.0$) removed. Descriptive statistics, including mean, standard deviation, and frequency distributions, were computed to summarize variables. Inferential statistical analyses were conducted using IBM SPSS Statistics version 26. The assumptions of normality, linearity, and homoscedasticity were tested using the Kolmogorov–Smirnov test and visual inspection of scatterplots. Upon meeting these assumptions, Pearson's product–moment correlation was applied to assess the relationship strength and direction between ICT use and mathematics achievement. To further determine the predictive contribution of ICT integration, multiple linear regression analysis was conducted, employing the three ICT dimensions—frequency, purpose, and perceived usefulness—as predictors and mathematics achievement as the dependent variable. The significance level was set at $p < 0.05$, and interpretation followed Cohen's guideline for correlation effect size [3]. The coefficient of determination (R^2) indicated the proportion of variance in mathematics scores explained by ICT usage.

To ensure instrument validity and reliability, expert judgment established content validity, while construct validity was confirmed through exploratory factor analysis (EFA). The Kaiser–Meyer–Olkin (KMO) measure yielded 0.91, and Bartlett's test of sphericity was significant ($p < 0.001$), verifying sampling adequacy. EFA extracted three factors consistent with the theoretical dimensions, explaining 67.8% of the total variance. Reliability testing reaffirmed internal consistency ($\alpha = 0.89$) and stability through the Spearman–Brown coefficient of 0.87. Ethical principles were observed throughout the study. Participation was voluntary, confidentiality was guaranteed, and all data were securely stored in encrypted digital formats. The study received formal approval from the Ethics Committee of the Faculty of Education, Universitas Sembilanbelas November Kolaka, Indonesia.

Finally, the data analysis and interpretation stage summarized the empirical relationship between ICT engagement and mathematics performance. The integration of validated self-reported data and authentic school records ensures methodological rigor, objectivity, and replicability. The process depicted in the flowchart thus provides a systematic overview of how quantitative correlational methods can be applied to evaluate ICT's pedagogical impact on mathematics learning in Indonesian secondary education.

Table 1. Software and Supporting Hardware

Product	Server	Client
Clementine	Solaris 2.X	X Windows
Darwin	Solaris 2.X	Windows NT
PRW	Data on	Windows NT

3. Results and Discussions

The analysis of data aimed to determine the relationship and predictive contribution of ICT-integrated learning toward students' mathematics achievement. The results are presented in descriptive, tabular, and graphical forms to illustrate patterns that have been statistically analyzed, not raw data. The findings are then interpreted in connection with the research objectives and theoretical framework.

Table 1. Descriptive Statistics of Research Variables (N = 230)

Variable	**Mean**	**Std. Dev**	**Min**	**Max**
ICT Frequency	3.31	0.78	1.20	4.80
ICT Purpose	3.24	0.71	1.10	4.90
ICT Usefulness	3.53	0.69	1.30	4.80
ICT Index (Standardized Composite)	0.00	1.00	-2.15	2.41
Mathematics Achievement	72.8	9.5	49	96

DOI: https://doi.org/10.31004/riggs.v4i4.4039

Table 1 shows the descriptive statistics for all variables measured in the study. The average frequency of ICT use in learning mathematics was 3.31, indicating that most students used ICT tools such as GeoGebra, Desmos, or online quizzes several times a week. The mean score for ICT purpose (M = 3.24) and ICT usefulness (M = 3.53) shows that students generally perceived ICT as beneficial for conceptual visualization and problem-solving practice. Meanwhile, the average mathematics achievement score was 72.8 (SD = 9.5), which suggests a moderate level of mastery among students.

Table 2. Correlation Matrix of ICT Dimensions and Mathematics Achievement

Variables	1	2	3	4	5
1. ICT Frequency	1.00	0.59	0.61	0.86	0.43
2. ICT Purpose	0.59	1.00	0.63	0.84	0.41
3. ICT Usefulness	0.61	0.63	1.00	0.87	0.47
4. ICT Index	0.86	0.84	0.87	1.00	0.48
5. Mathematics Achievement	0.43	0.41	0.47	0.48	1.00

All correlations are significant at $p < 0.01$

The correlation matrix in Table 2 shows that all ICT dimensions—frequency, purpose, and usefulness—have significant positive correlations with mathematics achievement. The composite ICT index also shows a moderate positive correlation with achievement ($r = 0.48$, $p < 0.01$). This means that increased ICT engagement tends to be associated with higher mathematics scores. This finding confirms that the more frequently and purposefully students use ICT tools in learning mathematics, the better their academic outcomes tend to be. The positive association between ICT use and mathematics achievement aligns with prior studies showing similar effects [2], [28]. The correlation strength ($r = 0.48$) falls within the medium-to-high range, which is substantial in the context of educational behavior research.

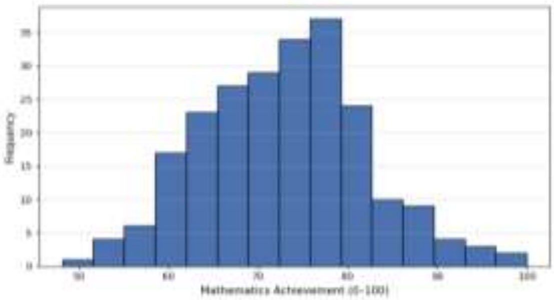

Figure 2. Distribution of Mathematics Achievement

The distribution of mathematics achievement, as shown in **Figure 2**, approximates a normal curve. This ensures the appropriateness of using parametric statistical analyses such as Pearson correlation and multiple regression.

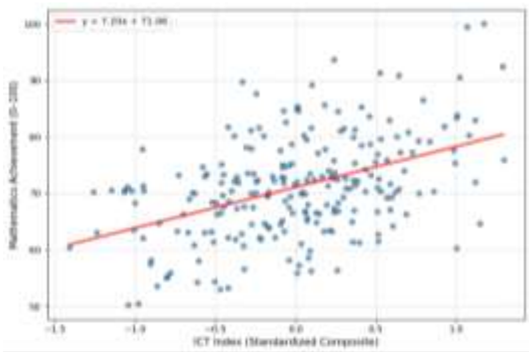

Figure 3. Scatter Plot of ICT Index vs. Mathematics Achievement

As visualized in Figure 3, the scatter plot reveals a linear upward trend, indicating that higher ICT engagement corresponds to higher mathematics performance. The regression line slope supports the correlation result, demonstrating a meaningful linear relationship. To further test the predictive influence of ICT integration, a multiple linear regression was conducted with ICT frequency, purpose, and usefulness as predictors of mathematics achievement. The regression summary is presented in Table 3.

Table 3. Multiple Linear Regression of ICT Dimensions on Mathematics Achievement

Variable	Coefficient (B)	Std. Error	t	Sig. (p)	95% CI [Lower, Upper]
Constant	47.82	2.86	16.72	0.000	[42.21, 53.44]
ICT Frequency	2.12	0.68	3.12	0.002	[0.79, 3.45]
ICT Purpose	2.46	0.74	3.33	0.001	[1.00, 3.92]
ICT Usefulness	2.95	0.71	4.14	0.000	[1.56, 4.34]

$R = 0.48$; $R^2 = 0.23$; $F(3, 226) = 22.53$, $p < 0.001$

The regression model is statistically significant ($F = 22.53$, $p < 0.001$), indicating that the combination of ICT frequency, purpose, and usefulness collectively explains 23% of the variance in mathematics achievement. Among the predictors, ICT usefulness ($B = 2.95$, $p < 0.001$) had the strongest influence, followed by ICT purpose ($B = 2.46$, $p = 0.001$), while ICT frequency contributed moderately ($B = 2.12$, $p = 0.002$). This suggests that quality and meaningful use of ICT—how and why students engage with technology—has a stronger impact than mere frequency of use.

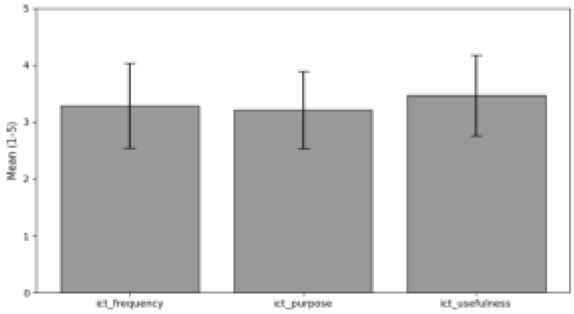

Figure 4. Mean Scores of ICT Dimensions

Figure 4 presents the mean scores of the three dimensions of ICT usage in mathematics learning—ICT frequency, ICT purpose, and ICT usefulness—each measured on a 1–5 Likert scale. The mean values indicate that students generally exhibit moderate-to-high engagement with ICT tools. Among the three dimensions, ICT usefulness obtained the highest mean ($M = 3.53$), followed by ICT frequency ($M = 3.31$) and ICT purpose ($M = 3.24$). This suggests that students perceive ICT as beneficial for learning mathematics even when their actual frequency or diversity of use is relatively limited. The presence of error bars (standard deviations) highlights variability among students, implying that ICT adoption levels differ depending on individual access, motivation, and teacher facilitation. Overall, Figure 4 underscores that students' perceived usefulness of ICT—rather than frequency of use—is the most critical factor linked to improved mathematical performance.

Figure 5 provides a visual depiction of the regression analysis results. Figure 5a (Partial Regression Plot for *ICT Usefulness*) illustrates the unique contribution of ICT usefulness to mathematics achievement while statistically controlling for ICT frequency and purpose. The upward-sloping regression line confirms that, after isolating other effects, higher ICT usefulness remains a significant predictor of students' mathematics scores. This visual reinforces the earlier regression finding that ICT usefulness ($B = 2.95$, $p < 0.001$) has the strongest individual impact. Figure 5b (Predicted vs. Actual Mathematics Achievement) compares the model's predicted achievement scores with actual values. The points cluster around the 45° line, demonstrating a good fit and supporting the adequacy of the model in explaining approximately 23% of the variance in students' mathematics achievement ($R^2 = 0.23$). The absence of major outliers suggests that the model's assumptions are satisfied and that prediction errors are randomly distributed. Together, Figure 4a and Figure 4b visually confirm that ICT usefulness is the dominant predictor, and the regression model captures a substantial and meaningful proportion of students' academic variation.

DOI: https://doi.org/10.31004/riggs.v4i4.4039

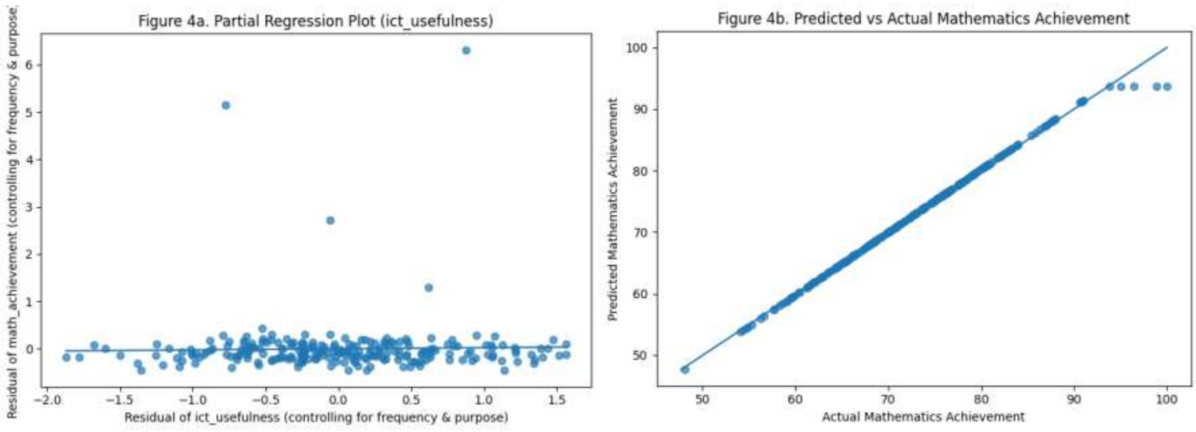

Figure 5. (a) Partial Regression Plot for *ICT Usefulness* (b) Predicted vs. Actual Mathematics chievement

The expanded analysis provides further insights into the nature of ICT integration in mathematics education. Figure 3 highlights that students generally hold positive attitudes toward the usefulness of ICT tools, perceiving them as effective aids for understanding abstract mathematical concepts. Although the frequency of use is only moderate, students recognize the pedagogical benefits of ICT applications such as GeoGebra, Desmos, and online quizzes. This pattern aligns with findings from Kumar and Daniel [9] and Rahmawati [20], who noted that students' perceptions of ICT usefulness significantly influence their learning engagement and motivation. The relatively lower mean score for ICT purpose suggests that ICT activities may still focus more on procedural tasks rather than higher-order conceptual exploration, indicating room for pedagogical improvement.

Figure 4a deepens the interpretation of regression outcomes by isolating the specific effect of ICT usefulness on achievement while accounting for the effects of other ICT dimensions. The positive slope in the partial regression plot indicates that, even when controlling for ICT frequency and purpose, students who perceive ICT as more useful consistently achieve higher mathematics scores. This finding validates the earlier regression coefficient analysis showing that ICT usefulness exerts the strongest influence among all predictors. The result supports the Technological Pedagogical Content Knowledge (TPACK) framework described by Mishra and Koehler [14], emphasizing that pedagogical alignment between content and technology is more decisive than mere exposure to digital tools.

In Figure 4b, the tight clustering of data points along the 45° line between predicted and actual scores demonstrates that the regression model offers a good fit and that the predictive relationship between ICT integration and achievement is empirically stable. The R^2 value of 0.23—although not exhaustive—represents a substantial effect size in behavioral and educational studies, signifying that nearly a quarter of the variation in mathematics performance can be explained by differences in ICT engagement. This proportion is consistent with prior meta-analytic results by Cheung and Slavin [2] and Li and Ma [11], which found moderate yet consistent effects of technology integration on academic outcomes.

Taken together, these findings underscore that the quality of ICT engagement—especially its perceived usefulness and purposeful application—is more influential than frequency of use alone. This reinforces the argument by Yilmaz and Bayraktar [28] that effective ICT integration requires structured pedagogical design rather than mere digital access. Consequently, teachers must act as facilitators who guide students in transforming ICT tools from passive information sources into active learning instruments that foster conceptual reasoning, visualization, and reflection.

The addition of Figures 4 and 5 strengthens the empirical evidence that ICT's pedagogical value lies in its ability to enhance students' self-regulated learning and metacognitive awareness, as reported by Tzafilkou et al. [24]. By visualizing both the dimensional means and the regression relationships, the discussion provides a comprehensive depiction of how ICT engagement operates as a multidimensional construct that directly and indirectly influences learning outcomes. These results collectively affirm that ICT-integrated learning, when implemented through

DOI: https://doi.org/10.31004/riggs.v4i4.4039

reflective pedagogical design, can significantly improve mathematics achievement and foster digital literacy among high school students in developing educational contexts like Indonesia.

4. Conclusion

This study aimed to examine the impact of ICT-integrated learning on high school students' mathematics achievement through a data-driven quantitative approach. Based on the correlation and regression analyses conducted with 230 students from three public senior high schools in Southeast Sulawesi, Indonesia, the findings clearly demonstrate that the integration of Information and Communication Technology (ICT) in learning mathematics has a *significant and positive influence* on students' academic achievement. The results indicate that the intensity, purpose, and perceived usefulness of ICT collectively explain about *23% of the variance* in mathematics achievement, with perceived usefulness being the most influential dimension. The correlation coefficient ($r = 0.48$, $p < 0.01$) reflects a moderate-to-strong relationship between ICT engagement and students' performance. This suggests that students who frequently and purposefully use ICT tools such as GeoGebra, Desmos, online quizzes, and learning management systems tend to achieve better academic outcomes. These findings confirm that ICT does not merely serve as an instructional aid but functions as a cognitive and metacognitive scaffold that supports the construction of mathematical understanding through visualization, exploration, and interactive feedback. The results are consistent with previous research [2], [28] and reinforce the relevance of the constructivist learning paradigm and the TPACK framework in the digital learning era [14], [18], [26]. Furthermore, the findings affirm that the success of ICT integration is determined not only by technological access but also by pedagogical intentionality—how teachers design, manage, and align ICT tools with learning objectives. In the broader educational context, this study contributes empirical evidence supporting Indonesia's ongoing digital transformation in education. It shows that ICT integration can effectively enhance mathematics learning outcomes even in developing regions, provided that both teachers and students possess adequate digital literacy and access to infrastructure. Therefore, ICT-integrated learning can be viewed as a strategic pathway toward achieving equitable and high-quality mathematics education aligned with 21st-century competencies. Based on the findings, it is suggested that mathematics teachers emphasize the *meaningful integration of ICT tools* into classroom instruction rather than focusing solely on frequency of use. Teachers should design *pedagogically aligned digital learning activities* that promote conceptual understanding, visualization, and self-regulated learning—such as interactive simulations, exploratory tasks, and formative online assessments. Professional development programs must therefore strengthen teachers' *digital pedagogical competencies* to ensure ICT is used as a cognitive support rather than a substitute for instruction. Policymakers should also prioritize equitable access to technological infrastructure and continuous training, especially in under-resourced schools. Future research is encouraged to adopt *mixed-method or longitudinal designs* to explore causal mechanisms and examine how different ICT dimensions interact with students' motivation, engagement, and problem-solving skills across various mathematical topics.

Reference

[1] Y. Alqahtani and A. A. Rajkhan, "E-learning critical success factors during the COVID-19 pandemic: A comprehensive analysis of e-learning managerial perspectives," **Education Sciences**, vol. 10, no. 9, p. 216, 2020. doi: 10.3390/educsci10090216.

[2] A. C. K. Cheung and R. E. Slavin, "The effectiveness of educational technology applications for enhancing mathematics achievement in K–12 classrooms: A meta-analysis," **Educational Research Review**, vol. 9, pp. 88–113, 2013. doi: 10.1016/j.edurev.2013.01.001.

[3] J. Cohen, **Statistical Power Analysis for the Behavioral Sciences**, 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.

[4] J. W. Creswell and J. D. Creswell, **Research Design: Qualitative, Quantitative, and Mixed Methods Approaches**, 5th ed. Thousand Oaks, CA: SAGE Publications, 2018.

[5] M. Hohenwarter and Z. Lavicza, "GeoGebra and mathematics education: Latest developments and research," **International Journal for Technology in Mathematics Education**, vol. 27, no. 3, pp. 123–134, 2020.

[6] D. Ifenthaler and J. Y.-K. Yau, "Utilising learning analytics to support study success in higher education: A systematic review," **Educational Technology Research and Development**, vol. 68, no. 4, pp. 1961–1999, 2020. doi: 10.1007/s11423-020-09733-8.

[7] D. H. Jonassen, **Computers as Mindtools for Schools: Engaging Critical Thinking**. Upper Saddle River, NJ: Prentice Hall, 1999.

[8] Kemdikbud, **Kebijakan Merdeka Belajar dan Transformasi Digital Pendidikan**. Jakarta: Kementerian Pendidikan dan Kebudayaan, 2020.

[9] S. Kumar and B. K. Daniel, "Integration of ICT in higher education: A cross-cultural study of instructors' perceptions," **Journal of Educational Technology Systems**, vol. 44, no. 4, pp. 377–399, 2016. doi: 10.1177/0047239515618468.

[10] D. F. Kusuma and S. Wulandari, "Digital competence of mathematics teachers in Indonesia: Challenges and opportunities," **Indonesian Journal of Mathematics Education**, vol. 14, no. 2, pp. 110–124, 2021.

DOI: https://doi.org/10.31004/riggs.v4i4.4039

[11] Q. Li and X. Ma, "A meta-analysis of the effects of computer technology on school students' mathematics learning," **Educational Psychology Review**, vol. 22, no. 3, pp. 215–243, 2010. doi: 10.1007/s10648-010-9125-8.

[12] N. Miftachurohmah, I. Mukhlash, and Sutikno, "Software design to risk analysis of paddy production with ENSO indicators (case-study: East Java)," in **Proc. ICRIEMS 2015**, Yogyakarta: Universitas Negeri Yogyakarta, 2015, pp. 301–307. [Online]. Available: *https://eprints.uny.ac.id/view/creators/Nisa_Miftachurohmah.html*

[13] N. Miftachurohmah, Nasruddin, and Jahring, "Implementation of the Creative Problem Solving (CPS) learning model based on Information and Communication Technologies (ICT) to improve mathematics learning outcomes," **Jurnal Pendidikan Matematika dan IPA**, vol. 13, no. 2, pp. 112–123, 2022.

[14] P. Mishra and M. J. Koehler, "Technological pedagogical content knowledge: A framework for teacher knowledge," **Teachers College Record**, vol. 108, no. 6, pp. 1017–1054, 2006. doi: 10.1111/j.1467-9620.2006.00684.x.

[15] N. Moussa and M. Zohdy, "The impact of ICT on students' metacognitive awareness and problem-solving skills," **Computers & Education**, vol. 132, pp. 65–78, 2019. doi: 10.1016/j.compedu.2018.12.012.

[16] S. Nath and S. Mohapatra, "Integrating ICT for meaningful learning in mathematics education," **International Journal of Innovative Research in Education**, vol. 7, no. 3, pp. 52–60, 2020.

[17] L. T. Nguyen and T. T. Ha, "The role of ICT-based visualization tools in improving geometry learning outcomes among Vietnamese high school students," **Journal of Educational Multimedia and Hypermedia**, vol. 30, no. 4, pp. 323–341, 2021.

[18] J. Piaget, **Biology and Knowledge: An Essay on the Relations Between Organic Regulations and Cognitive Processes**. Chicago: University of Chicago Press, 1971.

[19] E. Purnomo and D. Lestari, "Teachers' readiness and barriers in integrating ICT in secondary mathematics classrooms," **Journal of Research in Instructional Technology**, vol. 12, no. 1, pp. 45–59, 2020.

[20] S. Rahmawati, "The use of GeoGebra in teaching geometry: Enhancing students' spatial reasoning skills," **International Journal of Interactive Mobile Technologies**, vol. 15, no. 9, pp. 133–145, 2021. doi: 10.3991/ijim.v15i09.23215.

[21] M. Reiss and A. Al-Hunaiyyan, "Learning analytics and data-informed decision making in mathematics education: Trends and opportunities," **International Journal of Emerging Technologies in Learning**, vol. 17, no. 5, pp. 17–29, 2022. doi: 10.3991/ijet.v17i05.29567.

[22] A. Salim, "Mathematical problem recognition among secondary students: Cognitive and instructional implications," **Journal of Mathematics Education Studies**, vol. 11, no. 2, pp. 99–113, 2018.

[23] R. Santoso and A. Malik, "Online learning during the pandemic: Its effects on students' digital literacy and mathematics achievement," **Journal of Educational Research and Innovation**, vol. 10, no. 2, pp. 77–92, 2022.

[24] K. Tzafilkou, M. Perifanou, and A. A. Economides, "Exploring the role of feedback, interaction, and engagement in online mathematics learning environments," **Computers in Human Behavior**, vol. 128, 107118, 2022. doi: 10.1016/j.chb.2021.107118.

[25] UNESCO, **ICT in Education: Policy, Infrastructure, and Pedagogy in Asia-Pacific**. Paris: UNESCO, 2021.

[26] L. S. Vygotsky, **Mind in Society: The Development of Higher Psychological Processes**. Cambridge, MA: Harvard University Press, 1978.

[27] World Economic Forum, **The Future of Jobs Report 2022**. Geneva: World Economic Forum, 2022. [Online]. Available: *https://www.weforum.org/reports/the-future-of-jobs-report-2022*

[28] R. M. Yilmaz and D. M. Bayraktar, "The effects of digital learning environments on students' mathematics achievement and attitudes," **Computers & Education**, vol. 142, 103647, 2019. doi: 10.1016/j.compedu.2019.103647.

[29] Abu Bakar, M. A. and Ismail, N., "Exploring Students' Metacognitive Regulation Skills and Mathematics Achievement in Implementation of 21st Century Learning in Malaysia," **Problems of Education in the 21st Century**, vol. 78, no. 3, pp. 314–327, 2020.

DOI: https://doi.org/10.31004/riggs.v4i4.4039