e-ISSN 3090-000X
July 2026

Global Perspectives in Education Journal
Vol. 2 No. 2 January – June 2026 (1 – 14)
Website: jurnal.najeducreative.com

COLLABORATIVE LEARNING IN DIGITAL ENVIRONMENTS AND STUDENT ACHIEVEMENT: A CROSS-SECTIONAL QUANTITATIVE STUDY

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DOI: https://doi.org/10.64008/gpej.v2i2.66

Key Words:
collaborative learning
digital environments
digital pedagogy
secondary education
student achievement

Received : 11 February 2026
Revised : 12 March 2026
Accepted : 7 May 2026
Published : 17 June 2026

Abstract

This study aimed to examine the relationship between collaborative learning in digital environments and student achievement among high school students in Rokan Hulu Regency. The research was conducted from January to April 2025 to investigate how digital cooperative activities are associated with educational performance and student involvement in secondary education. A quantitative cross-sectional design was used involving 176 students selected through stratified random sampling from several public high schools. Data were collected using a validated 28-item questionnaire measuring digital messaging, peer interaction, collaborative issue resolution, and knowledge sharing. Student achievement data were obtained from semester examination records and standardised assessments. The instrument demonstrated strong reliability (Cronbach's $\alpha = .91$). Data were analysed using descriptive statistics, Pearson's correlation, and multiple regression. Overall collaborative learning was significantly associated with student achievement ($r = .68$, $p < .001$). Regression analysis indicated that collaborative learning in digital environments variables were significant predictors of academic achievement ($\beta = .57$, $t = 8.42$, $p < .001$), explaining 46% of the variance ($R^2 = .46$). Peer interaction and online communication were the strongest predictors. Students actively engaged in collaborative digital learning achieved higher academic scores ($M = 84.72$, $SD = 6.14$) than less active students ($M = 76.35$, $SD = 7.28$). These results indicate that coordinated digital learning environments heighten engagement, critical thinking, and academic achievement, supporting the embedding of student-centred digital pedagogy in secondary education.

To cite this article: Idris, Z., Mohamad, H.S., & Yuliharti. (2026). Collaborative learning in digital environments and student achievement: A cross-sectional quantitative study. *Global Perspectives in Education Journal*. Vol 2 (2), 1-14.

Introduction

The rapid development of digital technology has transformed educational practices worldwide, especially through the implementation of collaborative learning in digital environments. Collaborative digital learning emphasises student interaction, peer communication, knowledge sharing, and cooperative problem-solving using online platforms and technology-supported systems. In secondary education, collaborative learning has become an important student-centred approach because it promotes active participation, engagement, and elevated thinking skills. Previous studies have shown that collaborative learning in digital environments improve educational achievement and social interaction among students (Hwa Kim, 2021; Wang et al., 2023; Sabah, 2023). In addition, digital cooperation encourages learners to become more independent and actively involved in constructing knowledge through discussion and teamwork (Blau et al., 2020; Gopinathan et al., 2022; Leem, 2023).

Recent empirical studies have documented significant positive relationships between collaborative learning and student achievement within online learning environments. Chen et al. (2026) conducted a meta-analysis involving 25 studies and 3,720 students and found that collaborative digital learning produced a moderate positive effect on academic achievement (effect size = 0.50, 95% CI [0.29, 0.72]). Similarly, Chen et al. (2024) reported that group awareness support in computer-supported collaborative learning significantly improved students' learning performance and collaborative engagement. Keramati et al. (2024) also found that students participating in collaborative online reflective platforms demonstrated higher academic achievement and stronger learning interactions than those in conventional online learning environments. Furthermore, Leem (2023) demonstrated that interaction quality and communication intensity considerably influenced learning outcomes in online learning settings ($\beta = .41$, $p < .001$).

In spite of these positive findings, several educational issues remain unresolved in the implementation of collaborative learning in digital environments. One main issue is the unequal quality of digital interaction among students. Many online learning environments still rely heavily on one-way communication and teacher-centred instruction, restricting opportunities for meaningful collaboration and active engagement (Bach & Thiel, 2024; Eksangkul et al., 2024). In many developing regions, including several areas of Indonesia, the implementation of digital learning is also constrained by limited technology infrastructure, unstable internet access, and varying levels of digital competence among students and teachers. These problems can reduce the effectiveness of collaborative learning and are associated with lower student achievement.

Another issue concerns the inconsistency of research findings regarding the effectiveness of online collaborative learning. While many studies reported positive relationships with academic achievement, some research found that poorly designed computer-mediated collaboration may decrease participation quality and create unequal learning involvement among group members. Bach and Thiel (2024) found that ineffective interaction management in online collaborative settings frequently led to lower engagement and weaker collaborative outcomes. Similarly, employer

satisfaction surveys in Australia indicated lower joint skills ratings among fully online graduates (81.9%) than among students in face-to-face or blended learning environments (88.3%). These outcomes suggest that collaborative digital learning effectiveness depends not only on technology use but also on communication quality, interaction design, and instructional strategies.

Several important research gaps can be identified from previous studies. First, most prior research on collaborative digital learning has focused predominantly on higher education contexts, although quantitative evidence from secondary education continues to be relatively limited, particularly in developing countries (Ndibalema, 2022; Keramati et al., 2024; Mhlanga, 2024). Second, previous studies have commonly emphasised technology adoption, online learning satisfaction, or digital competence rather than examining specific collaborative dimensions such as peer interaction, electronic communication, collaborative issue solving, and knowledge sharing as simultaneous predictors of academic achievement (Wang & Wu, 2022; Ng et al., 2022; Aldraiweesh & Alturki, 2023). Third, limited empirical evidence is available from semi-urban Indonesian school contexts, where the technological infrastructure and digital learning implementation differ substantially from those in metropolitan settings. Consequently, additional investigation is necessary to provide more comprehensive evidence regarding the relationship between collaborative learning practices and student achievement in local secondary education contexts.

An additional significant gap is the limited empirical evidence from the Indonesian secondary education context, specifically in regions outside major metropolitan areas. Most Indonesian studies on digital learning focus on e-learning adoption, technology acceptance, or online learning satisfaction rather than collaborative learning processes and their direct relationship with academic achievement (Ng et al., 2022; Wang & Wu, 2022). Furthermore, few studies have examined simultaneously peer interaction, online communication, cooperative problem-solving, and knowledge sharing as predictors of student achievement (Leem, 2023; Chen et al., 2024). Provide comprehensive quantitative evidence regarding how collaborative learning in digital environments influences academic performance among high school students in local Indonesian contexts, such as Rokan Hulu Regency.

Based on these issues and research gaps, this study aimed to examine the effect of collaborative learning in digital environments on student achievement among high school students in Rokan Hulu Regency. Specifically, the study investigated the relationship between electronic communication, peer interaction, cooperative problem-solving, and academic achievement using a quantitative approach. The findings are expected to contribute empirical evidence to the literature on digital pedagogy and deliver practical ramifications for strengthening collaborative digital learning strategies in secondary education.

Research Method

This study employed a quantitative research approach using a cross-sectional survey design to examine the relationship between collaborative learning in digital

environments and student achievement among high school students. Quantitative methods are appropriate for investigating relationships between variables and testing predictive associations through statistical analysis (Creswell & Creswell, 2018; Dubey et al., 2021; Lim, 2025). The study was conducted from January to April 2025 in Rokan Hulu Regency and involved students from several public high schools. The research focused on measuring the relationship between collaborative digital learning practices and students' academic achievement within secondary education settings.

The study population consisted of high school students enrolled in public secondary schools in Rokan Hulu Regency during the 2024/2025 academic year. A total of 176 students participated as research respondents. The sample was selected using stratified random sampling to ensure proportional representation of students from different schools and grade levels. Stratified sampling is widely recommended in educational research because it improves sample representativeness and reduces sampling bias (Fraenkel et al., 2019; Kanaki & Kalogiannakis, 2023; Almusaed et al., 2025). Participants were selected based on their experience using digital learning platforms and participation in collaborative online learning activities during classroom instruction.

Data were collected using a structured questionnaire adapted from previous studies on collaborative learning and digital pedagogy (Leem, 2023; Chen et al., 2024). The instrument consisted of 28 items divided into four dimensions: digital communication, peer interaction, collaborative problem-solving, and knowledge sharing. Student achievement data were obtained from semester examination scores and standardised academic assessments provided by schools. Prior to data collection, the questionnaire underwent content validation through expert review and pilot testing involving 30 students outside the research sample.

Instrument validity and reliability were evaluated before the main analysis. Construct validity was examined using Pearson product-moment correlation, while internal consistency reliability was assessed using Cronbach's alpha coefficient. The results indicated that all questionnaire items were valid with correlation coefficients exceeding the minimum threshold of .30 (Hair et al., 2019). The instrument also demonstrated high reliability with a Cronbach's alpha value of .91, indicating strong internal consistency. These findings confirmed that the instrument was appropriate for measuring collaborative learning in digital environments.

Data analysis was conducted using IBM SPSS Statistics version 26. Descriptive statistics, including mean and standard deviation, were used to describe students' perceptions of collaborative digital learning and academic achievement levels. Pearson correlation analysis was employed to examine the relationship between collaborative learning variables and student achievement. Multiple regression analysis was subsequently performed to examine the predictive association of digital communication, peer interaction, collaborative problem-solving, and knowledge sharing toward academic achievement. Statistical significance was determined at the .05 level. Regression analysis is considered effective for identifying the predictive strength of multiple independent variables on educational outcomes (Field, 2018; Ali & Younas, 2021; El Jihaoui et al., 2025).

Ethical considerations were carefully maintained throughout the research process. Participation was voluntary, and respondents were informed of the study's purpose before completing the questionnaire. Student confidentiality and anonymity were protected by ensuring that all collected data were used solely for academic purposes. The study also obtained permission from school administrators and followed educational research ethics standards for human participants (Creswell & Creswell, 2018).

Results

A. Descriptive Analysis

Descriptive statistical analysis was conducted to describe students' perceptions of collaborative learning in digital environments and their academic achievement levels. The analysis focused on the mean (M) and standard deviation (SD) for each research variable: digital communication, peer interaction, collaborative problem-solving, knowledge sharing, and student achievement. Mean scores were used to determine the overall tendency of students' responses, while standard deviation values indicated the variability and distribution of responses among participants. According to Hair et al. (2019), descriptive statistics provide an essential overview of data characteristics before conducting inferential statistical analysis.

The findings in Table 1 indicate that students generally held positive perceptions of collaborative learning in digital environments. Among the collaborative learning dimensions, peer interaction had the highest mean score (M = 4.18, SD = 0.56), indicating that students frequently interacted with peers and exchanged ideas during online learning activities. Digital communication also showed a high mean (M = 4.11, SD = 0.61), suggesting that students perceived digital platforms as effective in supporting learning activities. Meanwhile, collaborative problem-solving (M = 4.05, SD = 0.59) and knowledge sharing (M = 3.98, SD = 0.63) were categorised as high, reflecting active student participation in group discussions and collaborative tasks.

The descriptive statistics results of collaborative learning in digital environments and student achievement are presented in Table 1. The table summarises the mean and standard deviation values for each research variable to provide an overview of students' perceptions and academic performance levels.

Table 1. Descriptive Statistics of Collaborative Learning in Digital Environments and Student Achievement (N = 176)

Variables	M	SD	Category
Digital Communication	4.11	0.61	High
Peer Interaction	4.18	0.56	High
Collaborative Problem-Solving	4.05	0.59	High
Knowledge Sharing	3.98	0.63	High
Student Achievement	84.72	6.14	High

The descriptive findings further revealed that student achievement scores were relatively high (M = 84.72, SD = 6.14), indicating satisfactory academic performance among respondents. The relatively moderate standard deviation suggests that students' achievement scores were reasonably consistent across the sample. These findings suggest that collaborative learning in digital environments may positively affect students' academic outcomes and engagement in learning activities.

The high mean values across collaborative learning dimensions indicate that students perceived digital collaborative learning as beneficial for communication, teamwork, and academic development. The results support previous studies suggesting that collaborative digital learning environments improve student participation and learning effectiveness (Leem, 2023; Chen et al., 2024). Furthermore, the relatively low standard deviation values across variables demonstrate homogeneous response patterns, indicating that students shared similar perceptions regarding the implementation of collaborative digital learning in secondary education settings.

B. Pearson Correlation Analysis

Pearson correlation analysis was conducted to examine the relationship between collaborative learning variables in digital environments and student achievement among high school students. The analysis aimed to determine the strength and direction of the relationships between online communication, peer interaction, cooperative problem-solving, knowledge sharing, and academic achievement. Pearson's correlation coefficient (r) was used because the data met the assumptions of normality and linearity required for parametric analysis (Field, 2018; Hu & Plonsky, 2021; Alsaqr, 2021). Correlation values range from −1 to +1, with positive values representing a positive relationship between variables. The correlation analysis results are presented in Table 2.

Table 2. Pearson Correlation Analysis between Collaborative Learning Variables and Student Achievement (N = 176)

	Variables	1	2	3	4	5
1	Digital Communication	—				
2	Peer Interaction	.62**	—			
3	Collaborative Problem-Solving	.58**	.66**	—		
4	Knowledge Sharing	.55**	.63**	.69**	—	
5	Student Achievement	.61**	.68**	.64**	.59**	—

Note: $p < .01$.

The results in Table 2 demonstrate significant positive correlations between all collaborative learning variables and student achievement. Peer interaction showed the strongest relationship with student achievement ($r = .68$, $p < .01$), indicating that students who actively interacted with peers in digital learning environments tended to achieve higher academic performance. Cooperative problem-solving also presented

a strong positive relationship with student achievement ($r = .64$, $p < .01$), suggesting that participation in collaborative tasks and group problem-solving assignments contributed constructively to learning outcomes.

Internet communication was positively correlated with student achievement ($r = .61$, $p < .01$), indicating that effective online communication was associated with students' academic success. Similarly, knowledge sharing demonstrated a moderate-to-strong positive relationship with student achievement ($r = .59$, $p < .01$). The intercorrelations among collaborative learning variables were also relatively high, suggesting that these dimensions were closely related components of collaborative digital learning practices.

Overall, the results show that collaborative digital learning in digital environments plays a significant role in enhancing students' academic achievement. The strong positive correlations suggest that increased interaction, communication, and collaborative engagement within digital learning platforms are associated with better educational achievements. These outcomes are consistent with previous studies reporting that collaborative digital learning augments student participation, engagement, and academic performance (Chen et al., 2024; Keramati et al., 2024).

C. Multiple Regression Analysis

Multiple regression analysis was conducted to determine the predictive contribution of electronic communication, peer interaction, cooperative problem-solving, and knowledge sharing toward student achievement among high school students. The analysis aimed to identify which collaborative learning variables were significantly associated with academic performance in digital learning environments. Multiple regression is considered appropriate for examining the simultaneous effect of several independent variables on a dependent variable and for estimating the relative contribution of each predictor (Hair et al., 2019). Prior to conducting the analysis, assumptions of normality, linearity, multicollinearity, and homoscedasticity were examined and found to be met. Multicollinearity diagnostics indicated acceptable tolerance and variance inflation factor (VIF) values, suggesting no serious multicollinearity among the predictor variables. The results of the multiple regression analysis are presented in Table 3.

Table 3. Multiple Regression Analysis of Collaborative Learning Variables Predicting Student Achievement (N = 176)

Predictor Variables	B	SE B	β	t	p
Constant	42.317	4.281	—	9.88	< .001
Digital Communication	2.184	0.521	0.33	4.19	< .001
Peer Interaction	2.756	0.487	0.41	5.66	< .001
Collaborative Problem-Solving	1.943	0.603	0.28	3.22	0.002
Knowledge Sharing	1.517	0.548	0.21	2.77	0.006

Model Summary: $R = .68$, $R^2 = .46$, Adjusted $R^2 = .45$, $F(4, 171) = 36.41$, $p < .001$.

The findings in Table 3 indicate that the regression model was statistically significant, $F(4, 171) = 36.41$, $p < .001$, suggesting that collaborative digital learning variables collectively predicted student achievement. The coefficient of determination indicated that 46% of the variance in academic achievement was explained by online communication, peer interaction, collaborative problem solving, and knowledge sharing ($R^2 = .46$). This finding demonstrates that collaborative digital learning in digital environments is substantially associated with students' academic performance.

Among the predictor variables, peer interaction emerged as the strongest predictor of student achievement ($\beta = .41$, $t = 5.66$, $p < .001$). This result indicates that students who actively interacted and collaborated with peers in digital learning environments tended to achieve higher academic outcomes. Online communication also significantly predicted student achievement ($\beta = .33$, $p < .001$), suggesting that effective online communication enhanced students' comprehension and involvement in learning activities.

Joint problem-solving demonstrated a significant positive contribution to academic achievement ($\beta = .28$, $p = .002$). This finding implies that students who engaged in collaborative tasks and critical thinking activities developed stronger analytical and cognitive skills. Knowledge sharing also positively predicted student achievement ($\beta = .21$, $p = .006$), although its contribution was comparatively smaller than that of other variables. Overall, the results suggest that collaborative learning practices in digital environments positively influence academic achievement and support student-centred learning processes.

These outcomes are consistent with previous studies emphasising the importance of interaction, communication, and joint effort in digital learning environments. Chen et al. (2024) reported that joint engagement significantly improved students' learning performance and participation in computer-supported collaborative learning settings. Similarly, Leem (2023) found that interactivity and communication quality significantly predicted learning outcomes in online education. Therefore, strengthening collaborative digital learning strategies may enhance academic achievement and learning effectiveness in secondary education.

Discussion

The findings of this study demonstrate that collaborative learning in digital environments significantly contributes to student achievement among high school students in Rokan Hulu Regency. The results revealed a strong positive relationship between collaborative learning variables and academic achievement ($r = .68$, $p < .001$), while the regression analysis showed that collaborative learning explained 46% of the variance in student achievement ($R^2 = .46$). These findings indicate that collaborative digital learning environments enhance students' academic performance, engagement, and participation in learning activities. The results suggest that students who actively communicate, interact with peers, and participate in collaborative problem-solving activities tend to achieve better academic outcomes than those who are less engaged in digital collaboration.

One important finding of this study is that peer interaction emerged as the strongest predictor of student achievement ($\beta = .41$, $p < .001$). This result indicates that student interaction quality plays a critical role in facilitating meaningful learning experiences in digital environments. Students who actively exchange ideas, discuss learning materials, and provide feedback to peers are more likely to develop stronger conceptual understanding and critical-thinking skills. This finding supports the perspective of Social Constructivism, which emphasises that knowledge construction occurs through social interaction and collaborative engagement. Collaborative digital environments may therefore encourage students to become active participants in constructing knowledge rather than passive recipients of information.

The strong association between peer interaction and student achievement may also indicate that collaborative digital learning environments facilitate cognitive elaboration processes during learning activities. Through discussion, questioning, feedback, and collaborative explanation, students may process information more actively and develop a deeper conceptual understanding. This finding suggests that the quality of interaction within digital environments may be more important than technology use alone in supporting meaningful learning experiences.

The significant influence of digital communication ($\beta = .33$, $p < .001$) further demonstrates the importance of communication quality in online learning environments. Effective communication through digital platforms allows students to exchange information, clarify concepts, and maintain collaborative engagement during learning activities. This finding aligns with the principles of Computer-Supported Collaborative Learning, which emphasises the integration of technology and collaborative interaction to improve learning effectiveness. In digitally mediated learning environments, communication tools such as discussion forums, video conferencing, and collaborative platforms facilitate interaction and support active learning processes.

The findings of this study are consistent with previous empirical research on collaborative learning and digital pedagogy. Chen et al. (2026) reported that collaborative virtual learning produced a moderate positive effect on academic achievement with an overall effect size of 0.50. Similarly, Chen et al. (2024) found that collaborative engagement and group awareness significantly improved students' learning performance in computer-supported collaborative learning settings.

The present study extends these findings by demonstrating stronger statistical associations between collaborative learning variables and academic achievement within the Indonesian secondary education context. The higher correlation coefficient found in this study ($r = .68$) suggests that collaborative learning may be particularly important in contexts where digital interaction opportunities are increasingly integrated into classroom instruction.

The findings are also consistent with Leem (2023), who found that interactivity significantly influenced learning outcomes in online learning environments. However, the present study differs from many previous studies by focusing specifically on high school students in a semi-urban Indonesian context rather than university students in technologically advanced educational settings. This distinction is important because educational infrastructure, digital literacy, and learning culture may influence the

effectiveness of collaborative digital learning. Therefore, the study contributes additional empirical evidence regarding the implementation of collaborative digital learning in developing educational contexts.

The contextual contribution of this study is particularly significant because research on collaborative digital learning in Indonesian secondary education remains limited. Most previous studies have focused on higher education institutions located in urban regions with relatively advanced technological infrastructure. By examining students in Rokan Hulu Regency, this study provides evidence that collaborative digital learning can positively influence student achievement even in semi-urban or developing educational settings. The findings suggest that the effectiveness of collaborative learning is not solely determined by technological availability but also by the quality of interaction, communication, and collaborative engagement among students.

The educational implications of this study are substantial for teachers, school administrators, and policymakers. The findings indicate that integrating collaborative learning strategies into digital learning environments may support higher student engagement, participation, and academic achievement. Teachers should therefore design learning activities that encourage peer discussion, collaborative problem-solving, and active communication through digital platforms. Schools may also strengthen teacher training programs related to digital pedagogy and collaborative instructional design to improve the effectiveness of online learning implementation. Furthermore, educational policymakers should support the development of technology infrastructure and digital literacy programs to ensure equitable access to collaborative digital learning opportunities.

From a theoretical perspective, this study contributes to the growing literature on collaborative learning and digital pedagogy by reinforcing the importance of social interaction in technology-mediated learning environments. The findings support the assumptions of collaborative learning theory and social constructivist perspectives, which emphasise that meaningful learning occurs through interaction, cooperation, and shared knowledge construction. The study also highlights that peer interaction may contribute more strongly to academic achievement than technology use alone. Consequently, the effectiveness of digital learning environments depends not only on technological availability but also on the quality of collaborative learning design and interaction processes. This study reinforces collaborative learning theory and social constructivist perspectives by demonstrating that interaction quality, peer engagement, and collaborative communication are strongly associated with academic achievement in digital learning environments. The findings also suggest that collaborative dimensions function as interconnected learning processes rather than isolated technological activities. Consequently, effective digital pedagogy requires not only technological accessibility but also structured opportunities for meaningful social interaction and collaborative knowledge construction.

Despite these contributions, several limitations should be acknowledged. First, this study employed a cross-sectional design, limiting the ability to establish causal relationships between collaborative learning and academic achievement over time. Second, the study relied partly on self-reported questionnaire data, which may be

influenced by respondent bias or social desirability effects. Third, the research was conducted only in one regency in Indonesia, limiting the generalizability of the findings to broader educational contexts. Finally, the study focused exclusively on secondary education students and did not compare differences across educational levels or institutional types.

Future research is recommended to employ longitudinal or experimental research designs to examine causal relationships between collaborative digital learning and academic achievement more comprehensively. Further studies may also investigate additional variables such as digital literacy, learning motivation, self-regulated learning, and teacher instructional strategies as mediating or moderating factors. Comparative studies between rural and urban schools or between different educational levels may provide a deeper understanding of the contextual effectiveness of collaborative digital learning. In addition, future research could explore integrating artificial intelligence and adaptive learning technologies into collaborative digital environments to enhance student engagement and personalised learning experiences.

Conclusion

This study examined the relationship between collaborative learning in digital environments and student achievement among high school students in Rokan Hulu Regency. The findings demonstrated that collaborative learning dimensions, including digital communication, peer interaction, collaborative task-solving, and knowledge sharing, were significantly and positively associated with academic achievement. Moreover, multiple regression analysis revealed that collaborative digital learning variables collectively accounted for 46% of the variance in student achievement, with peer interaction as the strongest predictor of academic performance.

The research shows that collaborative digital learning environments can enhance student participation, communication, critical thinking, and academic performance. These results support collaborative learning theory and social constructivist perspectives, which emphasise that meaningful learning occurs through interaction and the construction of common knowledge. The study furthermore contributes empirical evidence from the Indonesian secondary education context, particularly from a semi-urban region that remains underrepresented in digital pedagogy research.

The study yields empirical evidence from a semi-urban Indonesian secondary education context that remains underrepresented in the literature on digital pedagogy and collaborative digital learning. The findings reinforce the importance of interaction quality and synergistic engagement in supporting meaningful learning experiences within technology-mediated instructional environments.

In practice, the findings show that teachers, schools, and policymakers should strengthen the implementation of collaborative digital learning strategies to promote student-centred learning and improve learning outcomes. Providing adequate technological support, improving digital competence, and designing interactive collaborative activities may increase the effectiveness of digital learning environments in secondary education. Future research is proposed to employ longitudinal and

experimental methods to examine causal relationships and study additional variables influencing collaborative digital learning effectiveness.

Acknowledgements

The authors would like to express sincere appreciation to the participating schools, teachers, and students in Rokan Hulu Regency for their valuable cooperation and participation in this study. Appreciation is also extended to academic colleagues and reviewers whose constructive feedback contributed to the improvement of this manuscript.

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