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Investigating the Impact of Digital Learning Ecosystem Activities on Enhancing Pre-service Teachers' Mathematical Literacy

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Abstract

This study examined the influence of Digital Learning Ecosystem (DLE) activities on the mathematical literacy of pre-service teachers, emphasizing the connection between theoretical knowledge and practical application. A cohort of 30 pre-service mathematics educators was chosen via simple random sampling. The study utilized a quasi-experimental design using pretest-posttests to evaluate the efficacy of DLE activities. The tools comprised four lesson plans grounded in DLE principles, a mathematical literacy exam consistent with the OECD's PISA methodology, and a satisfaction survey to assess participants' engagement and perceptions. The results demonstrated a statistically significant enhancement ($p < 0.001$) in participants' mathematical literacy, accompanied by a large effect size (Cohen's $d = 1.34$), underscoring the considerable influence of DLE interventions. Participants indicated elevated satisfaction across multiple dimensions, including engagement ($M = 4.70$, $SD = 0.42$), perceived effectiveness ($M = 4.63$, $SD = 0.48$), and accessibility ($M = 4.55$, $SD = 0.51$). Qualitative feedback emphasized the significance of interactive components, including simulations, collaborative tools, and real-world problem-solving activities, in improving comprehension and motivation. These findings highlight the transformative capacity of DLE activities in pre-service teacher education, especially in enhancing critical thinking, problem-solving abilities, and mathematical literacy. The study provides important insights into the integration of digital tools into teacher training programs to prepare educators for increasingly digital classrooms. Future research should look at the long-term impacts and adaptability of DLE activities in different educational settings in order to improve their efficacy.

Keywords: Digital Learning Ecosystem, Mathematical Literacy, Pre-Service Teachers, Learning Activities, Blended Learning

INTRODUCTION

Teaching mathematics calls for not only intellectual knowledge but also the development of problem-solving abilities relevant for practical situations. Fundamental to disciplines including cognitive psychology, engineering, and computer science (Cheung & Slavin, 2016) basic mathematical ideas including probability, algorithms, and linear algebra provide a platform for efficient communication and transdisciplinary problem-solving. A thorough comprehension of these concepts enables students to interact deeply with complex concepts, encouraging interdisciplinary cooperation and effectively equipping them to address both academic and practical problems (National Research Council, 2012). Furthermore, proficiency in these theories not only improves the application of mathematical knowledge but also creates a solid platform for deeper engagement with difficult principles, facilitating multidisciplinary collaboration and real-world problem-solving (Cucker & Smale, 2001).

The Program for International Student Assessment (PISA) evaluates mathematical literacy as the capacity of pupils to utilize mathematical knowledge in practical, real-world scenarios. PISA assesses the mathematical literacy of 15-year-old pupils globally, focusing on theoretical comprehension and the application of mathematics in real-world situations (Shiel et al., 2007; OECD, 2018). This extensive assessment highlights disparities in educational systems and provides relevant statistics to improve pedagogical approaches, therefore bridging the gap between classroom teaching and practical application (Lie & Linnakyla, 2004). Closing this disparity is essential for arming pupils to meet demands of the society. In Thailand, consistently poor PISA ratings indicate systemic issues in teacher education, especially in rural regions facing a deficiency of trained educators. In these places, educators frequently instruct subjects beyond their areas of specialization, which considerably affects student performance (Pholphirul et al., 2023). Moreover, cultivating higher-order thinking skills (HOTS)—essential for excelling in evaluations such as PISA—necessitates proficient educators employing effective instructional techniques to promote critical thinking and problem-solving (Boobphan et al., 2021). Improving teacher training programs to emphasize these tactics is essential for enhancing student outcomes and closing the divide between theoretical understanding and actual application.

The development of the Digital Learning Ecosystem (DLE) offers mathematics education transforming opportunities. DLEs create flexible and interesting learning environments that combine digital tools and resources, therefore promoting individualized learning and teamwork (Chen & Jang, 2010). These environments encourage the development of critical 21st-century skills, like digital literacy and problem-solving, especially by involving pupils with multimedia information and instantaneous feedback. Rooted in learning theories like Vygotsky's Social Constructivism, which emphasizes interaction and collaboration (Kozulin et al., 2003) and Siemens' Connectivism, which holds that learning transpires through the exploration of digital networks (Siemens, 2005; Swan et al., 2015), Digital Learning Environments (DLEs) are vital for equipping students to thrive in a progressively digital global landscape. The study highlights the efficacy of DLE tools in improving engagement and conceptual comprehension in mathematics instruction (Thomas et al., 2019). Simulations, collaborative platforms, and multimedia information have demonstrated the ability to enhance both theoretical understanding and practical competencies.

Although the advantages of Digital Learning Ecosystems (DLEs) in enhancing engagement and conceptual comprehension are evident, there are still deficiencies in comprehending how DLEs specifically improve mathematical literacy, especially for pre-service educators. The majority of current research emphasizes general theoretical frameworks or the use of digital tools in wider educational methodologies. Ayres et al. (2020) illustrated the enhancement of engagement through multimodal digital tools; however, their study did not investigate the impact of these technologies on mathematical literacy within teacher education programs. Likewise, Higgins et al. (2015) emphasized the significance of digital platforms in enhancing retention, although they neglected to examine their influence on practical applications for pre-service teachers. Moreover, although PISA highlights the significance of practical mathematical applications (OECD, 2018), there is scant research investigating the capacity of DLEs to connect theoretical concepts with practical implementation in mathematics education. This integration is especially pertinent for teacher education programs, as pre-service teachers must cultivate their mathematical literacy and pedagogical competencies to effectively incorporate digital resources into their instructional methods.

Nuangchalerm (2016) underscores the significance of incorporating local knowledge into teacher education via service learning, illustrating its capacity to bridge academic comprehension with practical implementations. According to his studies, pre-service teachers who engage in community-based events help to increase their theoretical knowledge while developing public-mindedness and self-efficacy. According to Sein-Echaluce et al. (2017), including cooperative and adaptive learning models into digital environments will help to develop higher-order thinking skills (HOTS), which are absolutely vital for future teachers. This approach very closely aligns with the goals of Digital Learning Ecosystems (DLEs) by tying classroom instruction with practical experience. DLEs use interactive digital technologies to link theoretical knowledge with useful applications, therefore arming pre-service teachers with the skills needed to deftly handle the complexities of modern classrooms (Schneider et al., 2017). Nuangchalerm's study emphasizes the significance of community-based activities but fails to examine the unique function of digital technologies in connecting theoretical and practical knowledge in mathematics education. Likewise, Lopez et al. (2016) examine the efficacy of collaborative digital ecosystems, although they do not concentrate on their implementation in teacher education for mathematical literacy. This study examines how DLEs assist pre-service teachers in acquiring content knowledge and pedagogical skills essential for 21st-century education. This research illustrates how the incorporation of digital resources in teacher education programs enhances both theoretical comprehension and the practical application of mathematical concepts using Digital Learning Environments (DLEs). These innovations are essential for equipping future educators to address the requirements of

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progressively digital learning settings and enhance student achievement in worldwide evaluations like the Program for Worldwide Student Assessment (PISA).

This research examines the gaps in the current literature by exploring the impact of Digital Learning Ecosystem (DLE) activities on improving mathematical literacy in pre-service teachers. The study specifically investigates how DLE activities connect theoretical knowledge with practical application, assesses their efficacy in enhancing engagement and satisfaction, and examines their wider implications for teacher education programs. The study enhances the expanding corpus of research on the incorporation of digital resources in mathematics instruction by accomplishing these aims. Furthermore, it offers significant insights into how teacher training programs can enhance the preparedness of pre-service teachers to address the challenges of progressively digital learning environments and elevate student performance in international evaluations like the Program for International Student Assessment (PISA). The objective of these discoveries is to improve the training of pre-service teachers, enabling them to become proficient educators in the 21st century who can effectively employ digital resources to promote mathematical literacy and critical thinking skills.

METHOD

Research Design

This study employed a quasi-experimental research design. Quasi-experimental research conducted inside a single group. One Group Pretest-Posttest Design

Population and Sample

The study population comprised third-year Mathematics majors at a University in Thailand during the first semester of the 2024 academic year. The kids were allocated to two classrooms, each containing a diverse range of talents. Students with strong, intermediate, and poor mathematical skills made up this mix, therefore promoting a diversified learning environment. There were 52 students in total, evenly spaced between the two classrooms. Cluster sampling produced the research sample from this group. The sample consisted of one classroom with thirty students. The students were registered in the mathematics program at a University in Thailand for the first semester of the 2024 academic year. This sampling procedure guaranteed that the chosen classroom accurately represented the broader community, encompassing a comparable proportion of children with diverse abilities.

Instruments

This study assessed pre-service teachers' mathematical literacy in relation to Digital Learning Ecosystem (DLE) activities using three key metrics. The study used a blended learning approach and all of the instruments matched the Mathematical Literacy curriculum for third-year pre-service teachers.

Lesson Plans: Four lesson plans, amounting to 12 hours, were created utilizing a blended learning methodology that integrates DLE activities. The designs incorporated interactive simulations, online collaborative platforms, and multimedia tools to improve critical thinking, problem-solving, and the practical application of mathematical principles.

The Mathematical Literacy Assessment: Designed to gauge several aspects of mathematical literacy—including numeracy, numerical reasoning, and practical application—structured according to the OECD's PISA paradigm Comprising open-ended and multiple-choice questions, the evaluation was done both pre- and post-test to look at the impact of DLE events. The total points was fifty.

Satisfaction Questionnaire: This instrument assesses participants' contentment with the DLE activities. A 15-item Likert-scale questionnaire was utilized to assess accessibility, usability, engagement, and perceived efficacy. Open-ended questions yielded qualitative insights into participants' experiences, facilitating a more thorough assessment of the DLE activities' efficacy in promoting engagement and mathematical literacy.

Data Collection

Data were gathered in two phases: prior to and following the intervention. Participants first undertook a mathematics literacy evaluation to create a baseline. The experimental group subsequently engaged in DLE-based lessons for a duration of four weeks. Subsequently, the participants re-administered the assessment to determine alterations in literacy levels. A satisfaction questionnaire was distributed at the conclusion of the intervention to collect feedback on participants' experiences with the digital learning ecosystem.

Data Analysis

This study utilized three main instruments: lesson plans, a Mathematical Literacy Assessment, and a Satisfaction Questionnaire. Data analysis was performed utilizing suitable statistical methods to guarantee thorough and valid outcomes.

Lesson Plans: Three specialists evaluated the lesson plans to determine their congruence with learning objectives and efficacy in promoting mathematical literacy. The Index of Consistency (IOC) assessed expert consensus, yielding a perfect score (IOC = 1.00), so validating the plans (Linn, 2000). Qualitative feedback from experts, if accessible, will undergo thematic analysis to discern strengths and areas for enhancement.

Mathematical Literacy Assessment: Examining pre-test and post-test results allowed one to evaluate how Digital Learning Ecosystem (DLE) activities affected mathematical literacy of pupils. Mean, standard deviation, minimum, and maximum scores together captured participants' performance in descriptive statistics. Using a significance level of $p < 0.05$ (Cohen, 1988), a paired sample t-test was used to find statistically significant increases. While the reliability analysis using Cronbach's alpha ($\alpha = 0.804$) verified strong internal consistency, the item analysis included the difficulty index (p) and discrimination index (r) to assess test item efficacy. Calculated to evaluate the practical relevance of the improvement was the effect size (Cohen's d).

Satisfaction Questionnaire: The Satisfaction Questionnaire was scored using both quantitative and qualitative approaches. Likert-scale questions were used in descriptive statistics to gauge DLE activity satisfaction; Cronbach's alpha ($\alpha = 0.823$) was then reevaluated to validate dependability. The item analysis evaluated the discriminating efficacy of each question. Thematic analysis of open-ended responses yielded profound insights into participants' experiences, thereby contextualizing and enhancing the quantitative data.

RESULTS AND DISCUSSION

Lesson Plans

The lesson plans for the Mathematical Literacy in School Mathematics course were developed utilizing a blended learning methodology that incorporated Digital Learning Ecosystem (DLE) activities. Each plan, with a duration of four hours, encompassed 12 hours over four courses, employing a blend of in-person and online education. The sessions involved students in practical mathematical problem-solving activities, consistent with the blended learning model's ability to improve student engagement and comprehension of mathematical ideas (Garrison & Kanuka, 2004). By means of purposeful integration of synchronous and asynchronous strategies, students were able to review and interact with learning resources flexibly, therefore supporting different learning styles and independent learning (Graham, 2013). Moreover, including real-world examples enhanced students' ability to connect mathematical ideas to useful applications, a strategy supported by Anderson & Krathwohl's (2001) modification of Bloom's taxonomy, which emphasizes the need of application and critical thinking in education.

Table 1. Classroom Design, Tools Used, and Applications

Lesson Number	Mode	Digital Tools Used	Applications /Programs	In-Class Activities
1	Blended	Interactive simulations, online discussion forums	GeoGebra, Google Classroom	Group problem-solving, real-life mathematical applications
2	Blended	Multimedia resources, virtual collaboration tools	Zoom, Google Docs	Collaborative mathematical modeling, case study analysis

Lesson Number	Mode	Digital Tools Used	Applications /Programs	In-Class Activities
3	Online & In-Class	Dynamic graphs, instructional videos, interactive quizzes	Desmos, Kahoot (Free Version), YouTube	Application of quantitative reasoning in real-world scenarios
4	Blended	Online peer review platforms, simulations	Peergrade (Free Version), PhET Interactive Simulations	Peer assessment, reflection on applied mathematical problems

Table 1 demonstrates that each lesson plan included targeted applications designed to improve conceptual comprehension and engagement. GeoGebra enabled interactive simulations and dynamic mathematical modeling, which studies show greatly improves pupils' knowledge of geometric and algebraic concepts (Laborde et al., 2008). PhET Interactive Simulations gave students graphically dynamic tools to improve conceptual understanding by letting them dynamically engage with mathematical and scientific themes (Adams et al., 2008). These technologies effectively connect abstract mathematical theories with concrete real-world applications, enabling students to visualize and alter mathematical structures dynamically.

Collaborative tools like Zoom and Google Docs enhanced teamwork in virtual settings, underscoring the increasing significance of digital collaboration in contemporary education. Students were engaged in interactive quizzes and graphing activities using Kahoot and Desmos, therefore fostering a more dynamic and competitive learning environment—which has been demonstrated to increase student motivation and retention (Wang, 2015). Furthermore, digital tools like Padlet and Mentimeter provide more opportunities for formative assessment and teamwork, so helping students to reflect on their education and support serious conversations (Brown, 2020). Including both direct instruction and active learning strategies, the instructional strategies in these lesson plans followed the blended learning paradigm. While online activities, including simulations and multimedia materials, enhanced students' knowledge and prepared them for in-class conversations and group projects, students engaged in real problem-solving exercises in class. The implementation of blended learning strategies corresponds with the conclusions of Alammary et al. (2014), who determined that the strategic integration of traditional and digital pedagogical approaches improves student learning outcomes.

This study's lesson plans exemplify the utilization of blended learning and DLE resources to accomplish two objectives: improving conceptual comprehension and fostering critical thinking. Incorporating real-world problem-solving challenges guarantees that

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students comprehend mathematical theories and cultivate practical abilities, in accordance with 21st-century educational objectives (Means et al., 2013). Furthermore, these strategies facilitate the cultivation of higher-order thinking skills, as emphasized by Zohar & Dori (2003), who underscore the significance of teaching methods that compel students to utilize knowledge in intricate, real-world scenarios.

Mathematical Literacy Assessment: The pre-and post-test results of the Mathematical Literacy Assessment were analyzed in order to determine how Digital Learning Ecosystem (DLE) activities affected the mathematical literacy of students. Table 2 shows for both tests the mean, standard deviation, minimum, and maximum values.

Table 2. Descriptive Statistics for Pre-test and Post-test Scores

Test	N	Mean	Standard Deviation	Minimum	Maximum
Pre-test	30	15.20	3.54	10	22
Post-test	30	21.80	4.12	16	28

The findings demonstrate an elevation in scores from the pre-test (M = 15.2, SD = 3.54) to the post-test (M = 21.8, SD = 4.12). The lowest and maximum scores improved as well, suggesting that students benefited from the intervention regardless of their starting level of ability. This aligns with Hattie's (2009) studies, which emphasize how much treatments emphasizing engagement and interactive learning improve student performance.

A paired sample t-test was performed to ascertain the statistical significance of the score increase (Table 3). The results indicate a substantial disparity between pre-test and post-test scores, with a p-value < 0.001, so affirming the statistical significance of the intervention's effect.

Table 3. Paired Sample t-test Results for Pre-test and Post-test

Test	Mean	t-value	p-value
Pre-test	15.20		
Post-test	21.80	8.35	<0.001

Table 3 demonstrates that the t-value of 8.35 and a p-value of less than 0.001 signify a statistically significant enhancement in mathematical literacy following the DLE intervention. This confirms that the DLE activities improve the ability of the students to apply mathematical ideas in useful contexts. With Cohen's d = 1.34, the effect size shows a significant effect that denotes the major influence of DLE activities on raising mathematical literacy.

Moreover, data support Schunk and DiBenedetto's (2020) claim that digital settings enable self-regulated learning, so improving performance in mathematical issues. These results also support Kramarski & Mizrachi (2006), who found that the combination of digital resources with self-regulated learning approaches greatly improves mathematical thinking. These results confirm that DLE programs effectively link theoretical knowledge with practical applications, a necessary component underlined in international assessments including PISA.

Satisfaction Questionnaire: Designed post-intervention, the Satisfaction Questionnaire provided information on participants' experiences with the Digital Learning Ecosystem (DLE) activities. Examined by descriptive statistics, the survey consisted of fifteen Likert-scale items. Table 4 shows the mean and standard deviation for every important component of the DLE activities—that is, accessibility, usability, involvement, and perceived efficiency.

Table 4. Descriptive Statistics for Satisfaction with DLE Activities

Aspect	Mean	Standard Deviation
Accessibility	4.55	0.51
Ease of use	4.45	0.60
Engagement	4.70	0.42
Perceived effectiveness	4.63	0.48

Table 4 demonstrates that there is a high level of satisfaction for all facets of the DLE activities. Closely followed by perceived effectiveness (M = 4.63, SD = 0.48), suggesting that students considered the activities as both interesting and beneficial for their learning, engagement reached the highest satisfaction level (M = 4.70, SD = 0.42). Strong positive comments for accessibility (M = 4.55, SD = 0.51) and simplicity of use (M = 4.45, SD = 0.60) indicated that users of the digital tools found little challenges. Thematic analysis of the open-ended answers helped to identify common themes about participants' experiences with the DLE events. Several key ideas emerged:

- Engagement and Interactivity: Numerous participants observed that the interactive components, including simulations and online collaboration, markedly improved their engagement and drive for learning.

Participants valued the DLE exercises for facilitating the application of mathematical principles to real-world situations, hence enhancing their comprehension of the subject matter.

- Usability and Accessibility: Although the majority of participants deemed the digital tools user-friendly, a minority reported minor technical issues that hindered the learning experience.

This study's findings underscore the efficacy of Digital Learning Ecosystem (DLE) activities in improving mathematics literacy, engagement, and overall happiness among pre-service teachers. The pre-test and post-test scores demonstrate a notable enhancement in students' mathematical literacy following the DLE intervention, supported by a statistically

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significant t-value ($t = 8.35$, $p < 0.001$) and a substantial effect size (Cohen's $d = 1.34$). The findings align with prior research, like Pratiwi & Widjajanti (2020), which highlights the beneficial effects of blended learning and digital tools on student engagement and academic performance in mathematics education. The significant enhancement in mathematical literacy indicates that the incorporation of interactive simulations, online platforms, and multimedia resources can connect theoretical understanding with practical application of mathematical concepts, thereby strengthening students' critical thinking and problem-solving skills. The open-ended comments yielded profound insights, with students highlighting the significance of real-world applications and collaborative activities in enhancing their engagement and comprehension. This corroborates the findings of Sun & Rueda (2012), who observed that engagement in online learning environments is markedly improved by interactivity and the perceived relevance of activities.

The elevated satisfaction levels indicated in the Satisfaction Questionnaire further validate the efficacy of the DLE activities. Engagement attained the highest satisfaction level ($M = 4.70$, $SD = 0.42$), meaning that the use of interactive technologies including GeoGebra, PhET simulations, and Kahoot considerably raised students' eagerness to study. This study corresponds with the work of Deslauriers et al. (2019), which illustrates that active learning tactics enhance student engagement and yield better learning outcomes. The perceived efficacy ($M = 4.63$, $SD = 0.48$) indicates that students saw the digital tools as beneficial for fostering a deeper comprehension of mathematical topics, hence reinforcing the assertion that the incorporation of digital learning aids promotes the advancement of mathematical reasoning.

Alongside the quantitative findings, a qualitative thematic analysis of open-ended responses indicated that students appreciated the practical application of concepts, since the DLE activities enabled them to utilize mathematical knowledge in real-world contexts. This discovery corresponds with current data indicating that real-world problem-solving activities enhance higher-order thinking skills and bolster retention (Newmann et al., 1996). Furthermore, although simplicity of use and accessibility received high satisfaction ratings ($M = 4.55$, $SD = 0.51$ and $M = 4.45$, $SD = 0.60$, respectively), some students reported minor technical problems, which corresponded with difficulties reported in other research on digital learning environments (Akpen et al., 2024). These tiny disturbances underscore the necessity of ensuring that digital tools are user-friendly and seamlessly integrated into the educational process.

The DLE exercises raised students' mathematical literacy and markedly increased their engagement and happiness with the learning experience. The findings, in conjunction with the research of Prasertsang et al. (2024), show that by tying theoretical knowledge with practical application, the use of digital tools and real-world applications in educational environments can greatly enhance students' learning outcomes. This finding is consistent with Jonassen's (1999) studies on constructivist learning environments, which emphasizes the use of technology in allowing significant, practical problem-solving actions.

CONCLUSION

This study illustrates the efficacy of Digital Learning Ecosystem activities in improving pre-service teachers' mathematics literacy. DLE exercises cultivate critical thinking, enhance problem-solving abilities, and promote engagement by connecting theoretical knowledge with practical applications. These findings underscore the necessity of incorporating digital tools into teacher training programs to adequately equip educators for the requirements of contemporary classrooms. Future investigations should examine long-term effects and enhance DLE instruments to guarantee wider accessibility and usage. Displayed as illustrated in Figure 1.

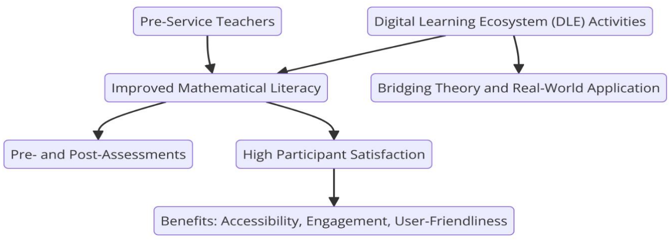

Figure 1. Diagram of The effectiveness of Digital Learning Ecosystem (DLE) activities in enhancing the mathematical literacy of pre-service teachers.

The results also have larger ramifications for practice and policy in education. Future teachers must be equipped for progressively digital classrooms by including DLE activities into their training. Still, even if the study shows promising findings, more study has to look at the long-term effects of DLE interventions and their relevance in different educational environments. Fixing technological problems and enhancing DLE operations would help to improve the learning process and thereby make these digital environments more efficient.

SUGGESTIONS

Use longitudinal research to assess how DLE interventions affect critical thinking and mathematical literacy going forward. Create intuitive digital tools for resource-limited environments to guarantee accessibility for varied student demographics. Broaden DLE integration across many disciplines, examining its effects on courses such as physics and chemistry.

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