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Learning cycle 9E integrated with instructional videos for enhancing numeracy literacy among prospective mathematics teachers: A quasi-experimental study

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Abstract

Background: Numeracy literacy is a fundamental competency that enables prospective mathematics teachers to interpret, analyze, and apply mathematical knowledge in authentic contexts. However, conventional mathematics instruction often emphasizes procedural proficiency rather than contextual reasoning, resulting in limited numeracy literacy development. Integrating constructivist learning with technology-enhanced instruction offers a promising approach to addressing this challenge.
Aim: This study aimed to investigate the effectiveness of the Learning Cycle 9E model integrated with instructional videos in enhancing the numeracy literacy of prospective mathematics teachers.
Method: A quasi-experimental study employing a pretest–posttest control group design was conducted with 50 undergraduate students enrolled in the Mathematics Education Study Program at Universitas Islam Negeri Raden Intan Lampung, Indonesia. Participants were assigned to an experimental group ($n = 25$) and a control group ($n = 25$). Data were analyzed using descriptive statistics, Shapiro–Wilk and Levene's tests, normalized gain (N-Gain), an independent samples t-test, and Cohen's d effect size.
Results: The experimental group outperformed the control group, achieving a higher posttest mean score (84.16 vs. 71.04) and N-Gain (0.62 vs. 0.31). A significant difference was identified between the groups ($t = 6.485$, $p < .001$), accompanied by a large effect size ($d = 1.84$).
Conclusion: Integrating the Learning Cycle 9E model with instructional videos effectively enhances numeracy literacy by fostering active knowledge construction, contextual mathematical reasoning, and meaningful technology-enhanced learning experiences in higher mathematics education.

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INTRODUCTION

Numeracy literacy has emerged as one of the most essential competencies in twenty-first-century education because it enables individuals to interpret, analyze, and apply mathematical knowledge in diverse real-life situations. In contemporary society, numeracy literacy extends beyond performing arithmetic calculations, encompassing the ability to reason mathematically, evaluate quantitative information critically, solve contextual problems, and make informed

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decisions based on data and evidence (Geiger et al., 2015). These competencies have become increasingly important as rapid technological development and digital transformation require individuals to process quantitative information accurately in academic, professional, and social contexts. Consequently, numeracy literacy has become a central objective of educational reforms worldwide, particularly within mathematics education, where learners are expected to develop competencies that support lifelong learning and active participation in an increasingly data-driven society (OECD, 2023). Despite its recognized importance, international assessments continue to reveal persistent weaknesses in students' numeracy literacy across various educational systems. The results of the Programme for International Student Assessment indicated that many students still struggle to formulate, employ, and interpret mathematics when confronted with authentic and non-routine problems requiring mathematical reasoning (OECD, 2023). Similarly, findings from the Trends in International Mathematics and Science Study (TIMSS) demonstrated that students generally perform better on procedural tasks than on contextual mathematical problems requiring conceptual understanding and analytical thinking (Bautista et al., 2026; Choi et al., 2026; Kalaam & Alex, 2026; Mokgwathi, 2026) . These findings suggest that conventional mathematics instruction, which frequently emphasizes procedural fluency and memorization, may not adequately facilitate the development of higher-order mathematical competencies necessary for numeracy literacy (Stacey, 2015). Consequently, there is an increasing need to design learning environments that encourage students to construct mathematical understanding actively while applying mathematical knowledge to authentic situations. Therefore, strengthening numeracy literacy has become a strategic priority for mathematics education, particularly in higher education institutions responsible for preparing future mathematics teachers.

The development of numeracy literacy requires instructional approaches that actively involve learners in constructing knowledge through exploration, discussion, reflection, and authentic problem-solving activities. Constructivist learning theory emphasizes that meaningful learning occurs when students actively connect new information with their prior knowledge through cognitive engagement and social interaction rather than passively receiving information from instructos (Le & Nguyen, 2024; Uddin et al., 2024). Accordingly, mathematics instruction should provide meaningful opportunities for students to investigate mathematical phenomena, collaborate with peers, justify their reasoning, and reflect upon their learning experiences. Learning environments that adopt constructivist principles have consistently been reported to improve higher-order thinking skills, conceptual understanding, and mathematical reasoning more effectively than traditional teacher-centered instruction (Khasawneh et al., 2023). One instructional model that strongly reflects these principles is the Learning Cycle 9E model, which extends the inquiry-based learning cycle into nine interconnected phases consisting of eliciting, engaging, exploring, explaining, elaborating, exchanging, evaluating, extending, and empowering (T.-C. Huang et al., 2025; Mang et al., 2021; Photo, 2025). Each phase is systematically designed to facilitate conceptual change by encouraging students to construct mathematical knowledge through inquiry, communication, collaboration, and reflection. Through these sequential learning activities, students are expected to develop a deeper understanding of mathematical concepts while strengthening their ability to solve contextual problems and communicate mathematical ideas effectively. Previous studies have demonstrated that learning cycle-based instruction contributes positively to students' conceptual understanding, academic achievement, critical thinking, and scientific reasoning across various educational contexts (Mekonnen et al., 2024; Nga et al., 2023; Riffert et al., 2021; Varoglu et al., 2023). These findings indicate that the Learning Cycle 9E model provides a promising pedagogical foundation for developing the multidimensional competencies underlying numeracy literacy. Nevertheless, maximizing the effectiveness of inquiry-oriented learning also requires instructional resources capable of presenting mathematical concepts in meaningful, contextual, and engaging ways.

Recent advances in educational technology have significantly transformed mathematics education by enabling more interactive, flexible, and student-centered learning environments. Digital technologies facilitate visualization, interaction, and immediate feedback that can improve students' engagement, conceptual understanding, and learning outcomes while accommodating diverse learning needs (Kong, 2021). Furthermore, technology-enhanced learning environments support multiple representations of mathematical concepts, allowing students to connect symbolic, graphical, numerical, and contextual forms of mathematical information more effectively (Demir, 2023; Shé et al., 2023; Sofroniou, 2025; Zengin, 2023). Consequently, educational technology has increasingly been recognized as an important component of mathematics instruction that supports the development of mathematical literacy and numeracy competencies (Çakıroğlu et al., 2024; Sakurai & Goos, 2023; St Omer et al., 2025). Among various digital learning resources, instructional videos have received considerable attention because they provide flexible access to learning materials while combining narration, visualization, animation, and contextual examples that facilitate conceptual understanding. Instructional videos also enable learners to review content repeatedly, regulate their own learning pace, and develop a deeper understanding of abstract mathematical concepts through multimedia representations (Atkinson et al., 2024; Elliot et al., 2020; Fyfield et al., 2022; M. C.-L. Huang et al., 2020; Trenholm, 2022; Wei et al., 2020). According to Multimedia Learning Theory, the integration of verbal and visual information promotes meaningful learning by reducing unnecessary cognitive load and strengthening cognitive processing (Fiorella & Mayer, 2018). Empirical studies have consistently demonstrated that instructional videos improve students' motivation, engagement, academic achievement, conceptual understanding, and mathematical problem-solving abilities across diverse educational settings (M. C.-L. Huang et al., 2020; Korntreff et al., 2026; Lo & Hew, 2021; Xu et al., 2025; Zaitoun et al., 2023). Moreover, technology-supported mathematics learning has been shown to facilitate numeracy development by providing meaningful visual contexts and interactive learning experiences that enhance students' mathematical. Therefore, integrating instructional videos with the Learning Cycle 9E model offers a promising technology-enhanced constructivist learning approach that has the potential to strengthen numeracy literacy through active inquiry, meaningful visualization, and authentic mathematical problem solving.

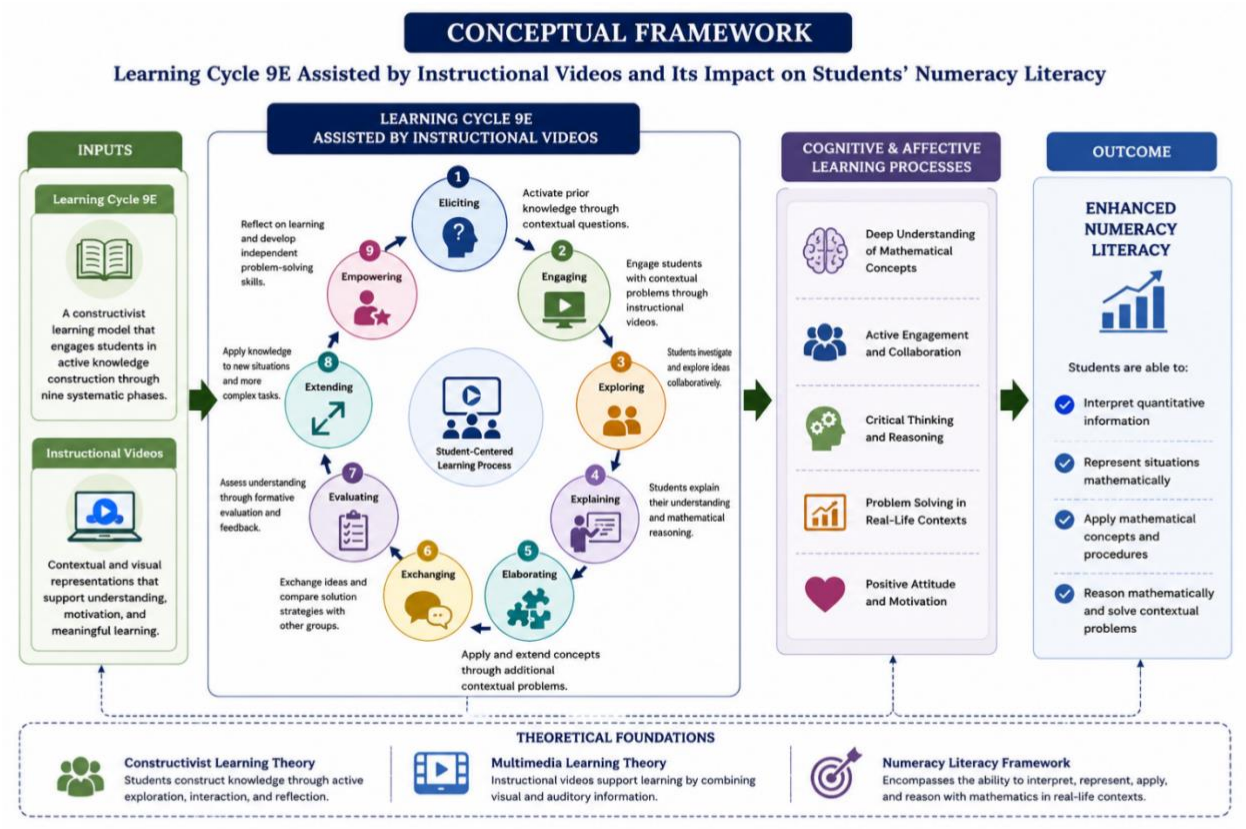

Figure 1. Conceptual Framework of Learning Cycle 9E Assisted by Instructional Videos

Although previous studies have consistently demonstrated the positive contributions of technology-enhanced learning, instructional videos, and constructivist pedagogies to mathematics education, important research gaps remain regarding their integrated implementation for developing numeracy literacy among prospective mathematics teachers. Existing studies on technology-enhanced mathematics learning have primarily focused on digital learning environments, embodied learning, virtual reality, flipped classrooms, and technology-supported instructional models to improve students' engagement, mathematical reasoning, and conceptual understanding rather than numeracy literacy as the primary learning outcome (Aksu & Zengin, 2022; Georgiou et al., 2023; St Omer et al., 2025; Young, 2023). Likewise, research on instructional videos has predominantly investigated video design principles, instructor presence, and the effectiveness of educational videos in improving learning performance and student engagement without embedding these media within a structured constructivist instructional model such as the Learning Cycle 9E (Henderson & Schroeder, 2021; Köse et al., 2021; Mayer et al., 2020; Polat, 2023). Meanwhile, studies concerning numeracy literacy have largely discussed its conceptual foundations, global perspectives, and general implications for mathematics education, while empirical investigations examining instructional interventions specifically designed to enhance numeracy literacy remain relatively limited (Grotlüschen et al., 2020; Pratiwi et al., 2024). Furthermore, research involving prospective mathematics teachers has mainly emphasized professional competence, lesson planning, classroom management, technology integration, and pedagogical development rather than strengthening numeracy literacy through innovative instructional approaches (Bozkurt & Yiğit Koyunkaya, 2022; Fitriati et al., 2023). Therefore, limited empirical evidence exists regarding the integration of the Learning Cycle 9E model and instructional videos within a technology-enhanced constructivist learning environment to improve numeracy literacy among prospective mathematics teachers. Addressing this gap, the present study investigates the effectiveness of combining the Learning Cycle 9E model with instructional videos as an innovative instructional strategy for fostering numeracy literacy in mathematics teacher education, thereby extending previous research by integrating pedagogical models, educational technology, and numeracy literacy into a single instructional framework.

Based on the identified research gap, this study aimed to investigate the effectiveness of integrating the Learning Cycle 9E model with instructional videos in enhancing the numeracy literacy of prospective mathematics teachers. Specifically, the study sought to determine whether students who learned through the Learning Cycle 9E model integrated with instructional videos achieved significantly higher numeracy literacy than those who received conventional mathematics instruction. The study also examined the extent to which this technology-enhanced constructivist learning approach improved students' ability to interpret quantitative information, construct mathematical representations, apply mathematical reasoning, and solve contextual problems. Furthermore, the research evaluated the magnitude of students' learning improvement using normalized gain (N-Gain) analysis and assessed the practical significance of the intervention through Cohen's effect size analysis. By integrating inquiry-oriented learning with multimedia-supported instruction, this study aimed to provide empirical evidence regarding the effectiveness of combining pedagogical innovation and educational technology in mathematics teacher education. The study was further intended to extend previous research that has predominantly investigated learning cycle models and instructional videos independently rather than as an integrated instructional approach for developing numeracy literacy. From a theoretical perspective, the findings were expected to strengthen the application of Constructivist Learning Theory and Multimedia Learning Theory in explaining how technology-supported inquiry-based learning facilitates numeracy literacy development. From a practical perspective, the study sought to provide mathematics lecturers and teacher educators with an evidence-based instructional strategy that supports meaningful, student-centered, and technology-enhanced mathematics learning. In addition, the findings were expected to contribute to the growing body of literature on numeracy literacy by demonstrating the educational value of integrating the Learning Cycle 9E model with instructional videos within higher education contexts. Ultimately, this study aims to provide both theoretical and practical contributions to the advancement of innovative mathematics education by promoting instructional practices that better prepare prospective mathematics teachers to foster numeracy literacy in their future classrooms.

LITERATURE REVIEW

Numeracy literacy has become a central component of mathematics education because it equips learners with the ability to interpret, analyze, and apply mathematical knowledge in authentic situations rather than merely performing procedural calculations. Contemporary perspectives define numeracy literacy as a multidimensional competence involving mathematical reasoning, quantitative interpretation, problem solving, and evidence-based decision-making across various personal, social, and professional contexts (Geiger et al., 2015). The Organisation for Economic Co-operation and Development (OECD) further conceptualizes numeracy literacy as the capacity to formulate, employ, and interpret mathematics for solving real-world problems, emphasizing its importance in preparing students for lifelong learning and active participation in society (OECD, 2023). Consequently, mathematics education has shifted from emphasizing procedural fluency toward fostering conceptual understanding and contextual mathematical thinking that support meaningful learning experiences. Recent studies have consistently reported that students frequently experience difficulties in transferring mathematical knowledge to unfamiliar situations despite demonstrating satisfactory procedural competence (Adeniji & Baker, 2022; Braithwaite & Sprague, 2021; Jäder & Johansson, 2025; Yap & Wong, 2024). Such findings indicate that classroom instruction should provide learning experiences that enable students to connect mathematical concepts with realistic contexts through inquiry, reasoning, and reflection. Numeracy literacy is particularly important in higher education because prospective mathematics teachers are expected to possess not only strong mathematical knowledge but also the pedagogical competence required to cultivate numeracy literacy among future learners. Accordingly, higher education institutions have increasingly emphasized instructional approaches that encourage active learning, critical thinking, and contextual problem solving to strengthen prospective teachers' professional competence. Several systematic reviews have also highlighted that developing numeracy literacy requires coherent instructional strategies integrating meaningful learning activities, authentic assessment, and technology-supported environments that promote higher-order thinking. Therefore, strengthening numeracy literacy has become a strategic priority in mathematics teacher education because it directly influences future teachers' capacity to design meaningful mathematics instruction and facilitate students' mathematical reasoning in authentic contexts.

Constructivist learning theory provides a strong theoretical foundation for developing instructional models that actively engage learners in constructing mathematical knowledge through exploration, collaboration, and reflection rather than passive information acquisition. Within this perspective, meaningful learning occurs when students integrate new experiences with prior knowledge, thereby facilitating conceptual change and deeper cognitive understanding. One instructional model that operationalizes constructivist principles is the Learning Cycle 9E model, which expands the traditional learning cycle into nine sequential phases comprising eliciting, engaging, exploring, explaining, elaborating, exchanging, evaluating, extending, and empowering (Pan et al., 2024; Wu et al., 2025). These interconnected phases encourage learners to investigate mathematical phenomena, communicate their reasoning, evaluate alternative solutions, and apply conceptual understanding in unfamiliar situations. Compared with conventional teacher-centered instruction, the Learning Cycle 9E model promotes greater learner autonomy, collaborative learning, and reflective thinking because students become active participants throughout the learning process. Previous empirical studies have consistently reported that learning cycle-based instruction significantly improves conceptual understanding, academic achievement, scientific reasoning, and critical thinking skills across diverse educational contexts (Joswick & Hulings, 2024; Riffert et al., 2021). More recent investigations have also demonstrated that inquiry-oriented instructional models contribute positively to students' mathematical communication, reasoning, and problem-solving abilities by encouraging learners to construct knowledge through meaningful interactions and authentic investigations (Karakoc et al., 2025; Khasawneh et al., 2023; Kumazah & Agyei, 2026; Sen et al., 2021). Nevertheless, existing studies have predominantly evaluated the effects of the Learning Cycle model on academic achievement and conceptual understanding rather than examining its contribution to numeracy literacy as a multidimensional educational outcome. Furthermore, limited attention has been devoted to integrating the Learning Cycle 9E model with digital learning resources capable of enriching inquiry activities and supporting visual representations of mathematical concepts. Therefore, the Learning Cycle 9E model remains a promising pedagogical framework for fostering numeracy literacy when combined with appropriate technology-enhanced learning strategies.

The rapid advancement of digital technology has transformed mathematics education by providing innovative instructional media capable of enhancing students' engagement, conceptual understanding, and independent learning experiences. Among various digital learning resources, instructional videos have become one of the most widely adopted educational technologies because they integrate narration, visualization, animation, and contextual examples within a flexible learning environment. Multimedia Learning Theory explains that learners process information more effectively when verbal explanations are integrated with relevant visual representations, thereby facilitating meaningful cognitive processing and reducing unnecessary cognitive load (AlShaikh et al., 2024; Bahari et al., 2023; Mayer, 2024; Noetel et al., 2022) (Fiorella & Mayer, 2018; Mayer, 2021). Accordingly, instructional videos enable students to visualize abstract mathematical concepts, regulate their learning pace, revisit difficult materials repeatedly, and strengthen conceptual understanding through multiple representations. Numerous empirical studies have demonstrated that instructional videos positively influence students' learning motivation, engagement, conceptual understanding, academic achievement, and mathematical problem-solving performance across various educational settings (M. C.-L. Huang et al., 2020; Shen, 2024; Zaitoun et al., 2023). Technology-enhanced mathematics learning has also been shown to improve students' mathematical reasoning by presenting authentic problems through dynamic and interactive digital environments that facilitate exploration and conceptual connections (Aksu & Zengin, 2022; Demir, 2023; Sofroniou, 2025; St Omer et al., 2025). Furthermore, digital learning environments encourage students to become more autonomous learners because they can interact with instructional materials according to their individual learning needs and cognitive readiness. Despite these educational benefits, previous studies have generally examined instructional videos as independent learning media rather than integrating them with structured constructivist instructional models that systematically guide inquiry-based learning. Consequently, the pedagogical potential of instructional videos may not be fully optimized when they are implemented without an instructional framework that actively promotes exploration, discussion, reflection, and contextual mathematical reasoning. Therefore, integrating instructional videos within the Learning Cycle 9E model offers a theoretically grounded technology-enhanced learning approach that is expected to strengthen numeracy literacy by combining multimedia-supported instruction with inquiry-oriented mathematical learning.

Although constructivist learning models and instructional videos have individually demonstrated positive effects on mathematics learning, their pedagogical integration remains relatively underexplored within mathematics education. Effective technology integration requires digital learning resources to be embedded within instructional models that actively engage learners in inquiry, collaboration, and reflection rather than functioning merely as supplementary teaching media (Al Mamun & Lawrie, 2023; Fitzgerald & Evans, 2024; Seprie et al., 2025). The Learning Cycle 9E model provides a structured pedagogical sequence that guides students from activating prior knowledge to applying newly acquired concepts in authentic situations, thereby creating meaningful opportunities for integrating multimedia resources into each learning phase. Within this framework, instructional videos can function as contextual learning stimuli during the engaging phase, visual explanatory resources during the explaining phase, and authentic problem-solving scenarios during the elaborating and extending phases. Such integration enables students to observe mathematical phenomena, discuss alternative solution strategies, and construct conceptual understanding through multiple representations supported by multimedia learning principles. From the perspective of Constructivist Learning Theory, combining inquiry-oriented learning activities with multimedia-supported instruction is expected to strengthen students' cognitive engagement because learners actively construct knowledge while interacting with contextual mathematical problems (Guruloo et al., 2026; Mei & Azid, 2026). Likewise, Multimedia Learning Theory suggests that presenting verbal explanations together with dynamic visual representations facilitates deeper conceptual processing than either modality alone (Alhazmi, 2024; Fiorella et al., 2020; Noetel et al., 2022; Ruf et al., 2022). Recent reviews of video-based learning have further emphasized that instructional effectiveness depends not only on video quality but also on instructional design and pedagogical integration within meaningful learning activities. Consequently, integrating the Learning Cycle 9E model with instructional videos may create a technology-enhanced constructivist learning environment that simultaneously promotes conceptual understanding, mathematical reasoning, and contextual problem-solving abilities. Therefore, this integrated instructional approach provides a strong theoretical foundation for improving numeracy literacy through active inquiry supported by meaningful digital learning experiences.

The theoretical foundation of this study is established through the integration of Constructivist Learning Theory, Multimedia Learning Theory, and technology-enhanced mathematics learning, providing a comprehensive framework for understanding how students develop numeracy literacy in digital learning environments. Constructivist Learning Theory explains that learners construct mathematical knowledge through active engagement, inquiry, reflection, and social interaction, making learning more meaningful than passive knowledge transmission. Multimedia Learning Theory complements this perspective by explaining how learners process verbal and visual information simultaneously to build coherent mental representations that facilitate conceptual understanding and long-term retention (Mayer, 2024; Staneviciene & Žekienė, 2025). Technology-enhanced mathematics learning further emphasizes that digital resources should be employed not merely to deliver instructional content but to support exploration, reasoning, collaboration, and authentic problem solving that strengthen mathematical competence. Previous studies have independently demonstrated that inquiry-based learning models improve conceptual understanding, while instructional videos enhance engagement, motivation, and academic achievement (Arici & Yilmaz, 2025; Chen et al., 2025; H.-W. Huang et al., 2024). Nevertheless, empirical evidence investigating the combined implementation of these instructional components to develop numeracy literacy among prospective mathematics teachers remains limited. Existing research has also predominantly evaluated mathematics achievement, conceptual understanding, or critical thinking without considering numeracy literacy as a multidimensional educational outcome that integrates reasoning, interpretation, representation, and contextual application. Accordingly, the present study positions itself at the intersection of constructivist pedagogy, educational technology, and numeracy literacy by examining the educational value of integrating the Learning Cycle 9E model with instructional videos within higher mathematics education. This conceptual integration is expected to provide a more comprehensive explanation of how technology-supported inquiry-based learning contributes to students' numeracy literacy development than previous studies examining each instructional component independently. Therefore, the proposed instructional framework not only addresses an important gap in the literature but also contributes to advancing theory and practice in technology-enhanced mathematics education by offering empirical evidence for designing meaningful learning environments that foster numeracy literacy among prospective mathematics teachers.

METHOD

Research Design

This study employed a quantitative approach using a quasi experimental method with a pretest posttest control group design. The design was selected to investigate the effectiveness of the Learning Cycle 9E model assisted by instructional videos in improving students' numeracy literacy. According to quasi experimental designs are appropriate for examining causal relationships in educational settings where random assignment is difficult to implement. Two groups were involved in the study: an experimental group that received instruction through the Learning Cycle 9E model assisted by instructional videos and a control group that received conventional learning. Both groups were administered a pretest before the treatment and a posttest after the intervention. The research design is presented as follows:

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	–	O_4

Where:
- O_1 = Pretest of numeracy literacy in the experimental group
- O_2 = Posttest of numeracy literacy in the experimental group
- O_3 = Pretest of numeracy literacy in the control group
- O_4 = Posttest of numeracy literacy in the control group
- X = Learning Cycle 9E assisted by instructional videos

The effectiveness of the intervention was evaluated by comparing students' numeracy literacy achievement before and after treatment as well as between the experimental and control groups.

Participants

The participants of this study consisted of 50 undergraduate students enrolled in the Mathematics Education Study Program at Universitas Islam Negeri Raden Intan Lampung, Indonesia. The participants were taking the Senior High School Mathematics (Mathematics for SMA/MA) course during the academic year of the study. The sample was selected using cluster random sampling because the participants were already organized into intact classes. Two classes were selected and assigned as the experimental and control groups. Each group consisted of 25 students. The experimental group was taught using the Learning Cycle 9E model assisted by instructional videos, whereas the control group received conventional lecture based instruction commonly implemented in mathematics learning. The participants had relatively similar academic backgrounds because they were enrolled in the same study program and attended the same course. Prior to the implementation of the treatment, both groups completed a numeracy literacy pretest to ensure initial comparability between groups.

Treatment Procedure

The intervention was conducted over eight meetings during one academic semester in the Senior High School Mathematics (SMA/MA Mathematics) course. Each meeting lasted approximately 100 minutes and focused on mathematical topics related to algebra, functions, systems of equations, and contextual problem solving. The experimental group received instruction through the Learning Cycle 9E model assisted by instructional videos, whereas the control group received conventional lecture based instruction. Prior to the intervention, both groups completed a numeracy literacy pretest to determine their initial abilities. During the treatment period, students in the experimental group participated in learning activities structured according to the nine phases of the Learning Cycle 9E model. Instructional videos were integrated into several phases to provide contextual mathematical situations, visual explanations, worked examples, and opportunities for reflection. At the end of the intervention, both groups completed a posttest to evaluate the improvement in numeracy literacy. The implementation of the Learning Cycle 9E model assisted by instructional videos is presented in Table 2.

Table 2. Implementation of Learning Cycle 9E Assisted by Instructional Videos

Phase	Learning Activities
Eliciting	Students' prior knowledge was activated through contextual questions related to real life situations.
Engaging	Students watched instructional videos presenting contextual mathematical problems to stimulate curiosity and motivation.

Exploring	Students worked collaboratively in small groups to investigate and solve mathematical problems presented in the videos.
Explaining	Students communicated their findings and mathematical reasoning, while the lecturer facilitated conceptual clarification.
Elaborating	Students solved additional contextual problems to deepen their understanding of mathematical concepts.
Exchanging	Students exchanged ideas and compared alternative solution strategies with other groups.
Evaluating	Students completed formative assessments and received feedback on their understanding.
Extending	Students applied mathematical concepts to new situations and more complex numeracy literacy tasks.
Empowering	Students reflected on their learning experiences and evaluated the usefulness of mathematical concepts in real life contexts.

The instructional videos used in this study were specifically designed to support numeracy literacy development. The videos incorporated contextual problems, graphical representations, mathematical modelling activities, and guided explanations aligned with the learning objectives. The integration of videos was intended to facilitate conceptual understanding, mathematical reasoning, and students' ability to connect mathematical knowledge with authentic situations.

Instruments

The numeracy literacy test was developed based on the numeracy literacy framework proposed by OECD (2023) and further informed by the dimensions of numeracy. Accordingly, the instrument measured four dimensions of numeracy literacy: interpretation of quantitative information, mathematical representation and modelling, mathematical reasoning, and contextual problem solving. The blueprint of the instrument is presented in Table 3.

Table 3. Blueprint of Numeracy Literacy Test

Dimension of Numeracy Literacy	Indicator	Item Number
Interpretation of quantitative information	Interpreting numerical, graphical, and tabular information in real life situations	1, 2
Mathematical representation and modelling	Representing contextual situations using mathematical models, equations, tables, or graphs	3, 4, 5
Mathematical reasoning	Analyzing relationships, making logical conclusions, and justifying mathematical arguments	6, 7
Contextual problem solving	Applying mathematical concepts and procedures to solve real world problems	8, 9, 10

An example of a numeracy literacy indicator is students' ability to interpret information presented in tables and graphs and use such information to make appropriate mathematical decisions in everyday contexts. Before being administered, the instrument underwent expert validation involving three experts in mathematics education. Content validity was evaluated using Aiken's V coefficient. Items with Aiken's V values greater than 0.80 were considered highly valid and suitable for implementation. The reliability of the instrument was assessed using Cronbach's Alpha coefficient. A reliability coefficient greater than 0.70 indicates acceptable internal consistency. In addition, item analysis was conducted to determine the difficulty index and discrimination index of each test item to ensure the quality of the assessment instrument. In addition to the numeracy literacy test, instructional videos were utilized as supporting learning media in the experimental group. The videos contained contextual mathematical problems, visual explanations, worked examples, and reflective activities aligned with the phases of the Learning Cycle 9E model. Prior to implementation, the instructional videos were validated by two experts in mathematics education to ensure content accuracy, instructional quality, and alignment with the learning objectives.

Data Analysis

Data analysis was conducted using descriptive and inferential statistical techniques with the assistance of IBM SPSS Statistics software. First, descriptive statistics were employed to summarize students' numeracy literacy scores, including the mean, standard deviation, minimum score, and maximum score for both the experimental and control groups. Second, prior to hypothesis testing, prerequisite analyses were performed. Data normality was examined using the Shapiro–Wilk test because the sample size in each group was fewer than 50 participants (Razali & Wah, 2011). A significance value greater than 0.05 indicated that the data were normally distributed. Homogeneity of variance was tested using Levene's Test. Data were considered homogeneous when the significance value exceeded 0.05. Third, students' improvement in numeracy literacy was analyzed using the normalized gain (N-Gain) score proposed by Hake (1999). The N-Gain score was calculated using the following formula:

$$N_{Gain} = \frac{Skor\ Post\ Test - Skor\ Pretest}{Skor\ Maksimal - Skor\ Pretest}$$

The N-Gain categories were interpreted as follows:

Table 4. N-Gain Category

Nilai *N-Gain*	Interpretasi
$0{,}70 \leq g \leq 1{,}00$	High
$0{,}30 < g < 0{,}70$	Moderate
$0{,}00 < g < 0{,}30$	Low

Fourth, hypothesis testing was conducted using the Independent Samples t-test to determine whether there was a statistically significant difference in numeracy literacy achievement between the experimental and control groups. The significance level was set at $\alpha = 0.05$. According to Field (2018), a significance value less than 0.05 indicates a significant difference between groups. Finally, effect size analysis was performed using Cohen's d to determine the magnitude of the treatment effect. Cohen (1988) suggested the following interpretation criteria:

Table 5. Effect Size Category

Cohen's d	Interpretation
0.20	Small Effect
0.50	Medium Effect
0.80 or higher	Large Effect

The inclusion of effect size analysis provides additional information regarding the practical significance of the Learning Cycle 9E model assisted by instructional videos in enhancing students' numeracy literacy beyond statistical significance alone.

Ethical Considerations

Prior to data collection, all participants were informed about the objectives and procedures of the study. Participation was voluntary, and students provided informed consent before taking part in the research. Confidentiality and anonymity of participants were maintained throughout the study, and all collected data were used solely for academic and research purposes.

RESULTS AND DISCUSSION

Results

Descriptive Statistics of Students' Numeracy Literacy

The descriptive statistics were calculated to provide an overview of students' numeracy literacy performance before and after the implementation of the Learning Cycle 9E model assisted by instructional videos.

Table 6. Descriptive Statistics of Numeracy Literacy Scores

Group	Test	N	Mean	SD	Minimum	Maximum
Experimental	Pretest	25	58.24	8.53	42	72
Experimental	Posttest	25	84.16	6.47	72	95
Control	Pretest	25	57.80	8.71	41	73
Control	Posttest	25	71.04	7.85	56	84

Table 6 shows that both groups had relatively similar pretest means, indicating comparable initial numeracy literacy abilities. The experimental group obtained a mean pretest score of 58.24, while the control group obtained 57.80. After the intervention, the mean posttest score of the experimental group increased substantially to 84.16, whereas the control group achieved a mean score of 71.04. This finding indicates that students who learned through the Learning Cycle 9E model assisted by instructional videos demonstrated greater improvement in numeracy literacy than those who experienced conventional learning.

Instrument Validity and Reliability

Prior to the implementation of the intervention, the numeracy literacy test was evaluated to ensure its validity and reliability. Content validity was assessed by three experts in mathematics education using Aiken's V coefficient, while reliability was measured using Cronbach's Alpha. The results of the instrument validation and reliability analysis are presented in Table 7.

Table 7. Results of Instrument Validity and Reliability

Instrument Aspect	Result	Category
Aiken's V	0.89	Highly Valid
Cronbach's Alpha	0.91	Excellent Reliability

Table 7 shows that the numeracy literacy test achieved an Aiken's V coefficient of 0.89, indicating a high level of content validity. This result suggests that the test items were highly relevant to the intended dimensions of numeracy literacy and adequately represented the constructs being measured. Furthermore, the Cronbach's Alpha coefficient was 0.91, indicating excellent internal consistency. According to Taber (2018), a reliability coefficient above 0.90 reflects a highly reliable instrument. Therefore, the numeracy literacy test was considered appropriate for assessing students' numeracy literacy and was subsequently administered as both the pretest and posttest in the study.

Normality Test

The Shapiro Wilk test was conducted to determine whether the data were normally distributed.

Table 8. Results of the Shapiro–Wilk Normality Test

Group	Test	Statistic	Sig.
Experimental	Pretest	0.964	0.522
Experimental	Posttest	0.972	0.693
Control	Pretest	0.959	0.431
Control	Posttest	0.968	0.611

Table 8 indicates that all significance values exceeded 0.05. Therefore, the data were normally distributed and met the normality assumption required for parametric statistical analyses.

Homogeneity Test

Homogeneity of variance was examined using Levene's Test.

Table 9. Results of Homogeneity Test

Variable	Levene Statistic	Sig.
Posttest Scores	0.483	0.490

The significance value of 0.490 was greater than 0.05, indicating that the variances of both groups were homogeneous. Therefore, the data satisfied the homogeneity assumption.

N-Gain Analysis

The N-Gain analysis was conducted to determine the magnitude of improvement in students' numeracy literacy.

Table 10. N-Gain Scores of Numeracy Literacy

Group	Mean N-Gain	Category
Experimental	0.62	Moderate
Control	0.31	Moderate

The experimental group achieved a mean N-Gain score of 0.62, which falls within the moderate category and approaches the upper threshold of the category. Meanwhile, the control group obtained a mean N-Gain score of 0.31, indicating lower improvement. These findings suggest that the Learning Cycle 9E model assisted by instructional videos contributed more effectively to improving students' numeracy literacy.

Independent Samples t-Test

The Independent Samples t-test was performed to determine whether there was a statistically significant difference between the posttest scores of the experimental and control groups.

Table 11. Results of Independent Samples t-Test

Variable	t	df	Sig. (2-tailed)
Posttest Scores	6.485	48	0.000

The significance value obtained was 0.000, which was lower than 0.05. Therefore, the null hypothesis was rejected. This result indicates a statistically significant difference between the numeracy literacy achievement of students taught using the Learning Cycle 9E model assisted by instructional videos and those taught through conventional instruction.

Effect Size Analysis

To determine the practical significance of the treatment, Cohen's d effect size was calculated.

Table 12. Effect Size Analysis

Variable	Cohen's d	Interpretation
Posttest Scores	1.84	Large Effect

The Cohen's d value of 1.84 indicates a large effect according to Cohen's (1988) criteria. This finding suggests that the Learning Cycle 9E model assisted by instructional videos had a substantial impact on students' numeracy literacy.

Discussion

The findings revealed that the Learning Cycle 9E model assisted by instructional videos significantly improved students' numeracy literacy. The substantial increase in the experimental group's posttest scores and N-Gain values demonstrates that the integration of constructivist learning principles and multimedia resources provides meaningful learning experiences that facilitate numeracy literacy development. The effectiveness of the Learning Cycle 9E model can be explained through the perspective of constructivist learning theory. Constructivism posits that learners actively construct knowledge by connecting new information with their prior experiences rather than passively receiving information from instructors. The sequential phases of the Learning Cycle 9E model provide opportunities for students to activate prior knowledge, explore mathematical ideas, discuss alternative solutions, and reflect on their understanding. Such learning experiences encourage students to build meaningful conceptual structures that support the interpretation and application of mathematical concepts in real life situations. As numeracy literacy requires students to understand, analyze, and utilize mathematical information in authentic contexts, constructivist oriented learning environments are particularly effective in fostering these competencies.

One explanation for these findings is that the Learning Cycle 9E model actively engages students throughout the learning process. During the eliciting and engaging phases, students activate prior knowledge and establish connections with new mathematical concepts. In the exploring and explaining phases, students construct knowledge through investigation, discussion, and reflection (Bassachs et al., 2020; Ng et al., 2022; Veine et al., 2020; Yu, 2023). Such learning experiences encourage deeper conceptual understanding and mathematical reasoning, which are essential components of numeracy literacy (Torres-Peña et al., 2025). The findings support previous studies indicating that learning cycle based instruction contributes positively to students' mathematical achievement and higher order thinking skills. That learning cycle approaches significantly improved academic performance across educational levels. That learning cycle implementation enhanced conceptual understanding and student engagement. The present study extends these findings by demonstrating that Learning Cycle 9E is also effective in improving numeracy literacy among prospective mathematics teachers.

Another factor contributing to the effectiveness of the intervention is the integration of instructional videos. Educational videos provide visual representations that facilitate students' understanding of abstract mathematical concepts and contextual problems. According to multimedia learning environments enhance cognitive processing by combining visual and verbal information. Emphasized that instructional videos can improve knowledge retention and conceptual understanding when designed according to multimedia learning principles. The contribution of instructional videos may be further explained through Multimedia Learning Theory. According to meaningful learning occurs when learners actively process information through both visual and verbal channels (Mayer, 2021). Instructional videos integrate narration, animations, diagrams, and contextual examples that facilitate the construction of mental representations of mathematical concepts. Such visual support helps students understand abstract mathematical ideas, recognize relationships among concepts, and apply mathematical procedures in problem solving situations. In the context of numeracy literacy, videos provide concrete illustrations of quantitative information and real world applications, making mathematical concepts easier to understand and utilize in authentic situations.

The findings may also be explained by Cognitive Load Theory, which suggests that instructional materials should be designed to optimize the limited capacity of working memory. Numeracy literacy tasks often require students to process multiple sources of information, including numerical data, graphical representations, and contextual information. Instructional videos can reduce extraneous cognitive load by presenting information in a structured and visually organized manner, thereby allowing students to focus on essential mathematical relationships and problem solving processes. Furthermore, the Learning Cycle 9E model supports gradual knowledge construction through its sequential learning phases, which may prevent cognitive overload and facilitate deeper understanding. Therefore, the integration of Learning Cycle 9E and instructional videos may create cognitively efficient learning environments that promote numeracy literacy development. The significant improvement observed in this study aligns with who reported that video based learning environments improved students' achievement and engagement. Similarly, that video supported mathematics learning positively affected students' academic performance. Also demonstrated that multimedia assisted learning increased students' motivation and learning outcomes. The present study contributes additional evidence by showing that instructional videos can specifically support numeracy literacy development when integrated within a structured pedagogical framework.

The effectiveness of the Learning Cycle 9E model assisted by instructional videos may also be explained through the lens of technology enhanced learning. Educational technology provides opportunities for students to access multiple representations of mathematical concepts, which facilitate conceptual understanding and problem solving abilities. Technology supported mathematics instruction has been shown to strengthen students' reasoning skills, engagement, and achievement. Furthermore, emphasized that technology enhanced learning environments can promote numeracy development by providing authentic and interactive learning experiences. The large effect size obtained in this study indicates that the intervention was not only statistically significant but also practically meaningful. This finding is consistent with recent studies highlighting the benefits of integrating technology and student centered learning models in mathematics education. The combination of Learning Cycle 9E and instructional videos appears to create a learning environment that encourages active participation, conceptual understanding, and contextual problem solving, all of which are central dimensions of numeracy literacy.

Moreover, the findings support the growing body of literature emphasizing the importance of numeracy literacy in higher education, particularly for prospective mathematics teachers. Future mathematics teachers are expected not only to master mathematical content but also to possess the ability to apply mathematics in real life contexts and facilitate numeracy literacy development among their future students. Therefore, innovative instructional approaches such as Learning Cycle 9E assisted by instructional videos may contribute to preparing future educators who are capable of promoting numeracy literacy in diverse educational settings.

Implications

The findings of this study provide important theoretical, pedagogical, and practical implications for the advancement of mathematics education, particularly in promoting numeracy literacy among prospective mathematics teachers. From a theoretical perspective, the study extends the application of Constructivist Learning Theory by demonstrating that meaningful knowledge construction is strengthened when inquiry-based learning is systematically supported through multimedia resources embedded within the Learning Cycle 9E framework. The findings also reinforce Multimedia Learning Theory by providing empirical evidence that the integration of verbal explanations, visual representations, and contextual mathematical situations enhances students' conceptual understanding and facilitates the development of numeracy literacy beyond procedural competence. Furthermore, the study contributes to the growing body of research on technology-enhanced mathematics education by illustrating that instructional technology becomes more effective when it is integrated within a coherent pedagogical model rather than being used as an isolated instructional medium. From a pedagogical perspective, the results suggest that mathematics lecturers should consider redesigning classroom instruction by incorporating the sequential phases of the Learning Cycle 9E together with carefully designed instructional videos that encourage exploration, discussion, reflection, and contextual problem solving. Such integration provides students with richer opportunities to connect mathematical concepts to authentic situations, thereby strengthening mathematical reasoning, representation, interpretation, and decision-making skills that constitute essential dimensions of numeracy literacy. The substantial effect observed in this study also indicates that technology-supported constructivist instruction can produce not only statistically significant improvements but also educationally meaningful learning outcomes that are relevant for higher education practice. Consequently, teacher education institutions may adopt this instructional approach to better prepare prospective mathematics teachers who are capable of designing innovative, student-centered, and technology-enhanced mathematics learning environments in their future classrooms. The findings further imply that curriculum developers should integrate numeracy literacy explicitly into mathematics teacher education curricula by emphasizing contextual mathematical tasks, inquiry-based learning activities, and digital instructional resources that reflect authentic educational challenges. In addition, educational policymakers may utilize the evidence generated by this study to support professional development programs that strengthen lecturers' competencies in integrating constructivist pedagogy with educational technology to improve mathematics learning quality. The instructional framework proposed in this study may also serve as a reference for developing other technology-supported learning models that integrate active learning strategies with multimedia resources across different mathematical topics and educational levels. Ultimately, this study provides empirical support for the proposition that integrating the Learning Cycle 9E model with instructional videos represents a sustainable instructional innovation capable of enhancing numeracy literacy while simultaneously preparing prospective mathematics teachers to respond effectively to the educational demands of an increasingly digital and data-driven society.

Limitations and Suggestions for Future Research

Despite demonstrating the effectiveness of the Learning Cycle 9E model integrated with instructional videos in enhancing numeracy literacy, this study has several limitations that should be considered when interpreting its findings. First, the study involved only 50 prospective mathematics teachers from a single university, which may limit the generalizability of the findings to other higher education institutions, educational systems, or student populations with different academic characteristics. Second, the quasi-experimental design employed intact classes rather than randomly assigning individual participants, making it difficult to eliminate all potential influences of pre-existing classroom differences despite the comparable pretest results. Third, the intervention was implemented within a single course over eight instructional meetings, and therefore the findings primarily reflect short-term learning outcomes rather than the long-term retention and transfer of numeracy literacy competencies. Fourth, the study focused exclusively on numeracy literacy as the primary dependent variable and did not examine other potentially influential outcomes, such as mathematical creativity, self-regulated learning, metacognitive awareness, learning motivation, collaborative skills, or digital competence. In addition, the assessment relied mainly on cognitive test scores, which may not fully capture students' learning processes, classroom interactions, or changes in their attitudes toward mathematics learning. Future research is therefore encouraged to involve larger and more diverse samples drawn from multiple universities or different educational contexts to improve the external validity and broader applicability of the findings. Longitudinal studies are also recommended to investigate whether improvements in numeracy literacy achieved through the Learning Cycle 9E model integrated with instructional videos can be sustained over extended periods and transferred to authentic professional teaching contexts. Moreover, future investigations should adopt mixed-methods or longitudinal research designs by combining quantitative analyses with classroom observations, interviews, learning analytics, or reflective journals to obtain a more comprehensive understanding of students' cognitive and affective learning experiences. Researchers are also encouraged to examine the effectiveness of this instructional approach across different mathematical domains, educational levels, and learner characteristics to determine the conditions under which the intervention produces the greatest educational benefits. Furthermore, future studies may integrate emerging educational technologies, including artificial intelligence, adaptive learning systems, virtual reality, augmented reality, or learning analytics, to investigate how intelligent digital environments can further strengthen numeracy literacy development within constructivist mathematics instruction. Collectively, these future research directions will contribute to a more comprehensive understanding of technology-enhanced constructivist learning and provide stronger empirical evidence for developing innovative instructional practices that foster numeracy literacy in mathematics education.

CONCLUSION

This study demonstrated that integrating the Learning Cycle 9E model with instructional videos is an effective instructional approach for enhancing the numeracy literacy of prospective mathematics teachers. The findings revealed that students who participated in the technology-enhanced constructivist learning environment achieved significantly higher numeracy literacy than those who experienced conventional lecture-based instruction, as reflected in superior posttest performance, higher normalized gain scores, and a statistically significant difference between the two groups. The large effect size further indicates that the instructional intervention produced not only statistical significance but also substantial educational benefits for students' numeracy literacy development. These findings suggest that combining inquiry-oriented learning with multimedia-supported instruction provides meaningful learning experiences that facilitate conceptual understanding, mathematical reasoning, contextual problem solving, and the interpretation of quantitative information. The results also support the theoretical assumptions of Constructivist Learning Theory by demonstrating that active knowledge construction through exploration, discussion, reflection, and collaborative learning contributes to deeper mathematical understanding. In addition, the findings reinforce Multimedia Learning Theory by showing that the integration of verbal explanations, visual representations, and contextual mathematical situations through instructional videos enhances students' cognitive processing and learning effectiveness. The study therefore extends previous research by providing empirical evidence that the educational value of instructional videos is maximized when they are systematically integrated into a structured pedagogical model such as the Learning Cycle 9E rather than implemented as standalone instructional media. From a mathematics education perspective, the study highlights the importance of designing technology-enhanced learning environments that actively engage students in authentic mathematical inquiry instead of emphasizing procedural knowledge alone. The proposed instructional approach also offers an effective strategy for strengthening the competencies required by prospective mathematics teachers to facilitate numeracy literacy in their future classrooms. Furthermore, the study contributes to the growing literature on technology-enhanced mathematics education by integrating constructivist pedagogy, multimedia learning, and numeracy literacy within a single instructional framework. These findings provide practical guidance for lecturers, curriculum developers, and teacher education institutions seeking evidence-based instructional innovations that promote meaningful mathematics learning in higher education. Overall, the study concludes that the integration of the Learning Cycle 9E model with instructional videos represents a pedagogically sound and empirically supported instructional innovation capable of improving numeracy literacy while preparing prospective mathematics teachers to meet the demands of mathematics education in an increasingly digital and data-driven society.

AUTHOR CONTRIBUTIONS STATEMENT

Siska Andriani contributed to conceptualization, methodology, investigation, formal analysis, data curation, writing the original draft, project administration, and served as the corresponding author.

Rizki Wahyu Yunian Putra contributed to conceptualization, methodology, supervision, validation, visualization, and writing through review and editing. Indah Resti Ayuni Suri contributed to investigation, instrument development, validation, data collection, formal analysis, and writing through review and editing. Abi Fadila contributed to data curation, software, statistical analysis, visualization, validation, and writing through review and editing. All authors contributed substantially to the conception and design of the study, critically reviewed the manuscript for important intellectual content, approved the final version of the manuscript, and agreed to be accountable for all aspects of the work.

REFERENCES

Adeniji, S. M., & Baker, P. (2022). Worked-examples instruction versus Van Hiele teaching phases: A demonstration of students' procedural and conceptual understanding. *Journal on Mathematics Education, 13*(2), 337–356. https://doi.org/10.22342/jme.v13i2.pp337-356

Aksu, N., & Zengin, Y. (2022). Disclosure of students' mathematical reasoning through collaborative technology-enhanced learning environment. *Education and Information Technologies, 27*(2), 1609–1634. https://doi.org/10.1007/s10639-021-10686-x

Al Mamun, M. A., & Lawrie, G. (2023). Student-content interactions: Exploring behavioural engagement with self-regulated inquiry-based online learning modules. *Smart Learning Environments, 10*(1), 1. https://doi.org/10.1186/s40561-022-00221-x

Alhazmi, K. (2024). The effect of multimedia on vocabulary learning and retention. *World Journal of English Language, 14*, 390. https://doi.org/10.5430/wjel.v14n6p390

AlShaikh, R., Al-Malki, N., & Almasre, M. (2024). The implementation of the cognitive theory of multimedia learning in the design and evaluation of an AI educational video assistant utilizing large language models. *Heliyon, 10*(3). https://doi.org/10.1016/j.heliyon.2024.e25361

Arici, F., & Yilmaz, R. M. (2025). Effects of augmented reality and video-based learning in inquiry-based science education on academic achievement and motivation to learn science. *Journal of Computer Assisted Learning, 41*(5), e70128. https://doi.org/10.1111/jcal.70128

Atkinson, A., Bell, P., De La Rosa, I., DeGeorge, T., Jonassen, L., Kokil, V., Lee, S., Malloy, M., Pinzon, K., Robertson, C., Savage, J. C., Shahbaz, R., Villanueva, O., Wludyga, J., & Morris, J. (2024). Student-created videos in online STEM education: A large, interdisciplinary, randomized control study. *Discover Education, 3*(1), 178. https://doi.org/10.1007/s44217-024-00283-8

Bahari, A., Wu, S., & Ayres, P. (2023). Improving computer-assisted language learning through the lens of cognitive load. *Educational Psychology Review, 35*(2), 53. https://doi.org/10.1007/s10648-023-09764-y

Bassachs, M., Cañabate, D., Nogué, L., Serra, T., Bubnys, R., & Colomer, J. (2020). Fostering critical reflection in primary education through STEAM approaches. *Education Sciences, 10*(12). https://doi.org/10.3390/educsci10120384

Bautista, G., Cacuyong, R., Lavicza, Z., Sabitzer, B., & Emara, M. (2026). Function art: Understanding the artistic transformation of mathematical functions through learning analytics. *Journal of Learning Analytics, 13*(1), 208–231. https://doi.org/10.18608/jla.2026.9037

Bozkurt, G., & Yiğit Koyunkaya, M. (2022). Supporting prospective mathematics teachers' planning and teaching technology-based tasks in the context of a practicum course. *Teaching and Teacher Education, 119*, 103830. https://doi.org/10.1016/j.tate.2022.103830

Braithwaite, D. W., & Sprague, L. (2021). Conceptual knowledge, procedural knowledge, and metacognition in routine and nonroutine problem solving. *Cognitive Science, 45*(10), e13048. https://doi.org/10.1111/cogs.13048

Çakıroğlu, Ü., Güler, M., Dündar, M., & Coşkun, F. (2024). Virtual reality in realistic mathematics education to develop mathematical literacy skills. *International Journal of Human-Computer Interaction, 40*(17), 4661–4673. https://doi.org/10.1080/10447318.2023.2219960

Chen, C., Rabu, S. N. A., & Jamiat, N. (2025). Enhancing physics learning achievement, motivation and inquiry skills in a flipped classroom: A structured inquiry-based virtual lab approach. *Journal of Baltic Science Education, 24*(1), 37–52. https://doi.org/10.33225/jbse/25.24.37

Choi, K. M., Mun, J., & Hand, B. (2026). Bridging reasoning in mathematics and science: A document analysis of applying and reasoning in the TIMSS assessment framework and the case for utilization of resources. *Educational Psychology Review, 38*(1), 22. https://doi.org/10.1007/s10648-025-10115-2

Demir, F. (2023). The relationship between active participation in mathematics classes and motivational regulation and critical thinking disposition.

Elliot, L., Gehret, A., Valadez, M. S., Carpenter, R., & Bryant, L. (2020). Supporting autonomous learning skills in developmental mathematics courses with asynchronous online resources. *American Behavioral Scientist, 64*(7), 1012–1030. https://doi.org/10.1177/0002764220919149

Fiorella, L., & Mayer, R. E. (2018). What works and doesn't work with instructional video. *Computers in Human Behavior, 89*, 465–470. https://doi.org/10.1016/j.chb.2018.07.015

Fiorella, L., Stull, A. T., Kuhlmann, S., & Mayer, R. E. (2020). Fostering generative learning from video lessons: Benefits of instructor-generated drawings and learner-generated explanations. *Journal of Educational Psychology, 112*(5), 895–906. https://doi.org/10.1037/edu0000408

Fitriati, F., Rosli, R., & Iksan, Z. H. (2023). Enhancing prospective mathematics teachers' lesson planning skills through lesson study within school university partnership program. *Journal on Mathematics Education, 14*(1), 69–84. https://doi.org/10.22342/jme.v14i1.pp69-84

Fitzgerald, M. S., & Evans, K. B. (2024). Integrating digital tools to enhance access to learning opportunities in project-based science instruction. *TechTrends, 68*(5), 882–891. https://doi.org/10.1007/s11528-024-00975-w

Fyfield, M., Henderson, M., & Phillips, M. (2022). Improving instructional video design: A systematic review. *Australasian Journal of Educational Technology, 38*(3), 155–183. https://doi.org/10.14742/ajet.7296

Geiger, V., Goos, M., & Forgasz, H. (2015). A rich interpretation of numeracy for the 21st century: A survey of the state of the field. *ZDM, 47*(4), 531–548. https://doi.org/10.1007/s11858-015-0708-1

Georgiou, A., Kotakis, S., Loukidis, D., & Ioannou, I. (2023). Case study of seismic assessment of a short irregular historic reinforced concrete structure: Time-history vs. pushover nonlinear methods. *Journal of Earthquake Engineering, 27*(16), 4761–4785. https://doi.org/10.1080/13632469.2023.2193652

Grotlüschen, A., Desjardins, R., & Liu, H. (2020). Literacy and numeracy: Global and comparative perspectives. *International Review of Education, 66*(2), 127–137. https://doi.org/10.1007/s11159-020-09854-x

Guruloo, T. N. M., Osman, K., & Tan, S. Y. (2026). Enhancing rural students' science process skills through structured inquiry engagement in a non-immersive virtual reality chemistry laboratory. *Pedagogical Research, 11*(3), em0269. https://doi.org/10.29333/pr/18771

Henderson, M. L., & Schroeder, N. L. (2021). A systematic review of instructor presence in instructional videos: Effects on learning and affect. *Computers and Education Open, 2*, 100059. https://doi.org/10.1016/j.caeo.2021.100059

Huang, H.-W., Mills, D. J., & Tiangco, J. A. N. Z. (2024). Inquiry-based learning and technology-enhanced formative assessment in flipped EFL writing instruction: Student performance and perceptions. *SAGE Open, 14*(2), 21582440241236663. https://doi.org/10.1177/21582440241236663

Huang, M. C.-L., Chou, C.-Y., Wu, Y.-T., Shih, J.-L., Yeh, C. Y. C., Lao, A. C. C., Fong, H., Lin, Y.-F., & Chan, T.-W. (2020). Interest-driven video creation for learning mathematics. *Journal of Computers in Education, 7*(3), 395–433. https://doi.org/10.1007/s40692-020-00161-w

Huang, T.-C., Chou, Y.-Y., Gao, Z.-Q., & Shu, Y. (2025). Exploring the effects of the 6E instructional model on learners' metacognitive behaviors in 3D modeling. *International Journal of Technology and Design Education, 35*(5), 1965–1997. https://doi.org/10.1007/s10798-025-09972-3

Jäder, J., & Johansson, H. (2025). Exploring students' conceptual understanding through mathematical problem solving: Students' use of and shift between different representations of rational numbers. *Research in Mathematics Education, 0*(0), 1–18. https://doi.org/10.1080/14794802.2025.2456840

Joswick, C., & Hulings, M. (2024). A systematic review of BSCS 5E instructional model evidence. *International Journal of Science and Mathematics Education, 22*(1), 167–188. https://doi.org/10.1007/s10763-023-10357-y

Kalaam, R. N. A., & Alex, J. K. (2026). Student readiness for TIMSS through the lens of mathematical proficiency: Evaluation of an instructional initiative for grades 5–8 in the UAE. *Eurasia Journal of Mathematics, Science and Technology Education, 22*(1), em2767. https://doi.org/10.29333/ejmste/17759

Karakoc, G., Alacaci, C., & Ayas, A. (2025). A strategy to engage students in inquiry-based learning of mathematics: Predict, observe and explain. *Instructional Science, 53*(5), 1195–1222. https://doi.org/10.1007/s11251-025-09733-8

Khasawneh, E., Hodge-Zickerman, A., York, C. S., Smith, T. J., & Mayall, H. (2023). Examining the effect of inquiry-based learning versus traditional lecture-based learning on students' achievement in college algebra. *International Electronic Journal of Mathematics Education, 18*(1), em0724. https://doi.org/10.29333/iejme/12715

Kong, Y. (2021). The role of experiential learning on students' motivation and classroom engagement. *Frontiers in Psychology, 12*. https://doi.org/10.3389/fpsyg.2021.771272

Korntreff, S., Bach, S., Altieri, M., & Prediger, S. (2026). Can interactive videos enhance understanding of variables as generalizers? Randomized controlled trial on engagement effects. *Technology, Knowledge and Learning*. https://doi.org/10.1007/s10758-026-09973-8

Köse, E., Taşlıbeyaz, E., & Karaman, S. (2021). Classification of instructional videos. *Technology, Knowledge and Learning, 26*(4), 1079–1109. https://doi.org/10.1007/s10758-021-09530-5

Kumazah, V., & Agyei, D. D. (2026). From classroom to long-term results: The impact of inquiry-based teaching on student achievement and retention in geometry. *International Journal of Science and Mathematics Education, 24*(2), 14. https://doi.org/10.1007/s10763-025-10640-0

Le, H. V., & Nguyen, L. Q. (2024). Promoting L2 learners' critical thinking skills: The role of social constructivism in reading class. *Frontiers in Education, 9*. https://doi.org/10.3389/feduc.2024.1241973

Lo, C. K., & Hew, K. F. (2021). Developing a flipped learning approach to support student engagement: A design-based research of secondary school mathematics teaching. *Journal of Computer Assisted Learning, 37*(1), 142–157. https://doi.org/10.1111/jcal.12474

Mang, H. M. A., Chu, H.-E., Martin, S. N., & Kim, C.-J. (2021). An SSI-based STEAM approach to developing science programs. *Asia-Pacific Science Education, 7*(2), 549–585. https://doi.org/10.1163/23641177-bja10036

Mayer, R. E. (2021). Evidence-based principles for how to design effective instructional videos. *Journal of Applied Research in Memory and Cognition, 10*(2), 229–240. https://doi.org/10.1016/j.jarmac.2021.03.007

Mayer, R. E. (2024). The past, present, and future of the cognitive theory of multimedia learning. *Educational Psychology Review, 36*(1). https://doi.org/10.1007/s10648-023-09842-1

Mayer, R. E., Fiorella, L., & Stull, A. (2020). Five ways to increase the effectiveness of instructional video. *Educational Technology Research and Development, 68*(3), 837–852. https://doi.org/10.1007/s11423-020-09749-6

Mei, Z., & Azid, N. (2026). An empirical analysis of case-based teaching in e-commerce education: Effects on learning motivation, classroom engagement, and career cognition among vocational students. *International Journal of Special Education, 41*(3s), 721–741.

Mekonnen, Z. B., Yehualaw, D. D., Mengistie, S. M., & Mersha, B. S. (2024). The effect of 7E learning cycle enriched with computer animations on students' conceptual understanding and overcoming misconceptions. *Journal of Pedagogical Research, 8*(2), 325–356. https://doi.org/10.33902/JPR.202425017

Mokgwathi, M. S. (2026). Closing the gap in early mathematics: Domain and cognitive insights from TIMSS 2023 in South Africa and Singapore. *F1000Research*. https://doi.org/10.12688/f1000research.172015.3

Ng, D. T. K., Luo, W., Chan, H. M. Y., & Chu, S. K. W. (2022). Using digital story writing as a pedagogy to develop AI literacy among primary students. *Computers and Education: Artificial Intelligence, 3*, 100054. https://doi.org/10.1016/j.caeai.2022.100054

Nga, N. T., Dung, T. M., Trung, L. T. B. T., Nguyen, T.-T., Tong, D. H., Van, T. Q., & Uyen, B. P. (2023). The effectiveness of teaching derivatives in Vietnamese high schools using APOS theory and ACE learning cycle. *European Journal of Educational Research, 12*(1), 507–523. https://doi.org/10.12973/eu-jer.12.1.507

Noetel, M., Griffith, S., Delaney, O., Harris, N. R., Sanders, T., Parker, P., del Pozo Cruz, B., & Lonsdale, C. (2022). Multimedia design for learning: An overview of reviews with meta-meta-analysis. *Review of Educational Research, 92*(3), 413–454. https://doi.org/10.3102/00346543211052329

OECD. (2023). *PISA 2022 results (Volume I): The state of learning and equity in education*. PISA. https://doi.org/10.1787/53f23881-en

Pan, Y., Wang, L., & Zhu, Y. (2024). Strategic questioning for formative assessment in TEFL: Insights from blended synchronous learning environments. *Humanities and Social Sciences Communications, 11*(1), 1519. https://doi.org/10.1057/s41599-024-04086-y

Photo, P. (2025). Teaching experiences connected to the implementation of inquiry-based practical work in primary science classrooms. *Research in Science Education, 55*(6), 1493–1516. https://doi.org/10.1007/s11165-025-10235-3

Polat, H. (2023). Instructors' presence in instructional videos: A systematic review. *Education and Information Technologies, 28*(7), 8537–8569. https://doi.org/10.1007/s10639-022-11532-4

Pratiwi, S. A., Peni, N. R. N., & Prabowo, A. (2024). Study on literacy numeracy towards students' logic mathematics: A literature review. *Numeracy, 11*(1), 58–69. https://doi.org/10.46244/numeracy.v11i1.2601

Riffert, F., Hagenauer, G., Kriegseisen, J., & Strahl, A. (2021). On the impact of learning cycle teaching on Austrian high school students' emotions, academic self-concept, engagement, and achievement. *Research in Science Education, 51*(6), 1481–1499. https://doi.org/10.1007/s11165-020-09918-w

Ruf, V., Küchemann, S., Kuhn, J., & Klein, P. (2022). Comparison of written and spoken instruction to foster coordination between diagram and equation in undergraduate physics education. *Human Behavior and Emerging Technologies, 2022*(1), 5860936. https://doi.org/10.1155/2022/5860936

Sakurai, J., & Goos, M. (2023). Revisiting tools in numeracy learning: The role of authentic digital tools. *Frontiers in Education, 8*. https://doi.org/10.3389/feduc.2023.1291407

Sen, C., Ay, Z. S., & Güler, G. (2021). The effectiveness of inquiry-based learning on middle school students' mathematics reasoning skill. *Athens Journal of Education, 8*(4), 417–440. https://doi.org/10.30958/aje.8-4-5

Seprie, Wuryandani, W., & Muthmainah. (2025). Transforming primary education: Balancing social skills and academic achievement through global inquiry-based learning models. *Frontiers in Education, 10*. https://doi.org/10.3389/feduc.2025.1512274

Shé, C. N., Fhloinn, E. N., & Bhaird, C. M. an. (2023). Student engagement with technology-enhanced resources in mathematics in higher education: A review. *Mathematics, 11*(3). https://doi.org/10.3390/math11030787

Shen, Y. (2024). Examining the efficacies of instructor-designed instructional videos in flipped classrooms on student engagement and learning outcomes: An empirical study. *Journal of Computer Assisted Learning, 40*(4), 1791–1805. https://doi.org/10.1111/jcal.12987

Sofroniou, A. (2025). Advancing conceptual understanding: A meta-analysis on the impact of digital technologies in higher education mathematics. *Education Sciences, 15*(11). https://doi.org/10.3390/educsci15111544

St Omer, S. M., Evers, K., Wang, C.-Y., & Chen, S. (2025). Technology-enhanced mathematics learning: Review of the interactions between technological attributes and aspects of mathematics education from 2013 to 2022. *Humanities and Social Sciences Communications, 12*(1), 1079. https://doi.org/10.1057/s41599-025-05475-7

Stacey, K. (2015). The international assessment of mathematical literacy: PISA 2012 framework and items. In S. J. Cho (Ed.), *Selected regular lectures from the 12th International Congress on Mathematical Education* (pp. 771–790). Springer. https://doi.org/10.1007/978-3-319-17187-6_43

Staneviciene, E., & Žekienė, G. (2025). The use of multimedia in the teaching and learning process of higher education: A systematic review. *Sustainability, 17*(19). https://doi.org/10.3390/su17198859

Torres-Peña, R. C., Peña-González, D., Lara-Orozco, J. L., Ariza, E. A., & Vergara, D. (2025). Enhancing numerical thinking through problem solving: A teaching experience for third-grade mathematics. *Education Sciences, 15*(6). https://doi.org/10.3390/educsci15060667

Trenholm, S. (2022). Media effects accompanying the use of recorded lecture videos in undergraduate mathematics instruction. *International Journal of Mathematical Education in Science and Technology, 53*(11), 3015–3043. https://doi.org/10.1080/0020739X.2021.1930221

Uddin, M. M., Chew, R. S. Y., Mc Neill, L., Islam, M. N., Awoyemi, I., & Sharmin, T. (2024). Infusing cognitivist and constructivist practices in teaching American plays to develop students' critical thinking skills. *The International Journal of Pedagogy and Curriculum, 32*(1), 165–192. https://doi.org/10.18848/2327-7963/CGP/v32i01/165-192

Varoglu, L., Yilmaz, A., & Sen, S. (2023). Effect of 5E learning cycle assisted with concept maps on conceptual understanding. *Pedagogical Research, 8*(3). https://doi.org/10.29333/pr/13167

Veine, S., Anderson, M. K., Andersen, N. H., Espenes, T. C., Søyland, T. B., Wallin, P., & Reams, J. (2020). Reflection as a core student learning activity in higher education: Insights from nearly two decades of academic development. *International Journal for Academic Development, 25*(2), 147–161. https://doi.org/10.1080/1360144X.2019.1659797

Wei, X., Cheng, I.-L., Chen, N.-S., Yang, X., Liu, Y., Dong, Y., Zhai, X., & Kinshuk. (2020). Effect of the flipped classroom on the mathematics performance of middle school students. *Educational Technology Research and Development, 68*(3), 1461–1484. https://doi.org/10.1007/s11423-020-09752-x

Wu, Y., Kanji, M., & Ou, G. (2025). From socialization to internalization: Tracing knowledge co-construction through sequential discourse interaction acts in high school English learning. *Frontiers in Education, 10*. https://doi.org/10.3389/feduc.2025.1664093

Xu, X., Broadbent, J., & Zhang, Q. (2025). Cultivating mathematical mindset via online video interventions: A mixed-methods investigation in Chinese higher education. *Frontiers in Psychology, 15*. https://doi.org/10.3389/fpsyg.2024.1494702

Yap, J. B. K., & Wong, S. S. H. (2024). Deliberately making and correcting errors in mathematical problem-solving practice improves procedural transfer to more complex problems. *Journal of Educational Psychology, 116*(7), 1112–1128. https://doi.org/10.1037/edu0000850

Young, J. R. (2023). The role of technology in enhancing urban mathematics education. *Journal of Urban Mathematics Education, 16*(2), 1–13. https://doi.org/10.21423/jume-v16i2a589

Yu, H. (2023). Reflection on whether ChatGPT should be banned by academia from the perspective of education and teaching. *Frontiers in Psychology, 14*. https://doi.org/10.3389/fpsyg.2023.1181712

Zaitoun, E., Shana, Z., Shater, A., Naser, K., & Mukattash, Z. (2023). Does flipping the classroom with videos and notetaking promote high school students' performance in mathematics? *Eurasia Journal of Mathematics, Science and Technology Education, 19*(6), em2274. https://doi.org/10.29333/ejmste/13200

Zengin, Y. (2023). Students' understanding of parametric equations in a collaborative technology-enhanced learning environment. *International Journal of Mathematical Education in Science and Technology, 54*(5), 740–766. https://doi.org/10.1080/0020739X.2021.1966848