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MEME-based Assemblr Edu Microlearning Enhance Student's Cognitive Ability

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Abstract. The growing demand for flexible, interactive, and cognitively engaging digital learning requires instructional models that align with the learning characteristics of Generation Z and Alpha students. This study aimed to examine the effect of microlearning supported by the Assemblr Edu application and structured through a Multi-Entry Multi-Exit (MEME) approach on students' cognitive abilities in Mathematics Education. A quantitative quasi-experimental design was employed using a non-equivalent pretest–posttest control group design. The participants were 68 third-semester students from the Elementary School Teacher Education Program at STKIP Muhammadiyah Blora, consisting of 35 students in the experimental class and 33 students in the control class. The experimental class received microlearning activities using the MEME-based Assemblr Edu application, whereas the control class received conventional instruction. Data were collected through cognitive ability tests and analyzed using the Liliefors normality test, F-test for homogeneity, independent-samples t-test, and normalized gain analysis. The findings showed that the experimental class achieved a higher posttest mean score (78.22; SD = 9.03) than the control class (68.41; SD = 11.82). The t-test result indicated a significant difference between groups, with t-value = 3.43 exceeding t-table = 2.00. The normalized gain score of the experimental class was 0.51, compared with 0.31 in the control class, indicating stronger cognitive improvement. These results demonstrate that MEME-based Assemblr Edu microlearning positively affects students' cognitive abilities. The novelty of this study lies in integrating microlearning, augmented reality-based digital media, and the MEME learning pathway in Mathematics Education. This study contributes an empirically tested instructional model for improving cognitive learning outcomes among preservice elementary school teachers.

Keywords: *Microlearning; Augmented Reality Learning; Assemblr Edu; Multi-Entry Multi-Exit Learning; Mathematics Cognitive Performance*

INTRODUCTION

By 2025, microlearning has been positioned as one of the most influential approaches for supporting contemporary students because it offers brief, focused, and accessible learning experiences that correspond to dynamic learning habits (Termansen et al., 2023). Students with dense academic and social routines require environments that allow them to access essential concepts quickly while maintaining sufficient depth for conceptual mastery (Kohnke, 2024). This urgency is relevant for Generation Z and Alpha learners, who are accustomed to digital interaction, immediate feedback, and visual information. As Generation Z is projected to represent a substantial proportion of the global workforce, learning systems are expected to provide flexibility, relevance, and professional development aligned with learner needs (Jain, 2025; Labibah, 2025; Widiayanti et al., 2022). Microlearning responds to this need by dividing complex

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content into manageable units that may improve engagement, retention, and knowledge transfer (Olivier, 2021).

Learning quality is influenced by curriculum policy, institutional support, infrastructure, teacher competence, and student characteristics, yet teacher–student interaction remains central to meaningful learning. Contemporary students differ from previous generations in their preferences for autonomy, multimodal content, and technology-enhanced interaction (Raslie & Ting, 2021). Broader generational studies indicate that differences in attitudes, values, and learning behavior emerge from social, cultural, and technological contexts, although individual and socioeconomic factors continue to shape learning outcomes (Kyle Chine R et al., 2025). Therefore, teacher education programs must prepare prospective teachers to design instruction that responds to students' cognitive, affective, and technological profiles. In mathematics education, this demand is crucial because abstract concepts require mediated representations, scaffolded practice, and active construction of meaning.

Despite the availability of digital learning resources, many mathematics education courses still face persistent challenges in helping students develop higher cognitive abilities. Cognitive ability involves mental processes related to understanding, remembering, applying, analyzing, evaluating, and creating knowledge, including the capacity to process information, connect concepts, solve problems, and make logical judgments (Clemente et al., 2024; Situmorang, 2018). Examples of cognitive activity include observing, relating ideas, evaluating events, thinking logically, and interpreting information, all of which are essential for mathematical reasoning (Ernest et al., 2016; Lopez, 2024; Mamolo, 2022; Nugroho & Fitri, 2016). Prior studies have shown that cognitive ability is associated with academic achievement, motivation, self-regulation, and problem-solving performance (Asare et al., 2025; Lavrijsen et al., 2021; Preckel & Scherrer, 2025; Wang & Chung, 2024). However, conventional lecture-based instruction often provides limited opportunities for individualized pacing, repeated interaction with visual objects, and immediate exploration of mathematical ideas. Consequently, students may experience fragmented understanding, reduced interest, and difficulty transferring concepts into teaching contexts.

A general solution to this problem is the adoption of technology-supported learning models that combine flexible access, interactive content, and student-centered pedagogy. Microlearning offers an instructional structure in which materials are presented as compact units such as short videos, infographics, interactive objects, and formative quizzes, enabling students to focus on specific competencies without excessive cognitive load (Dahiya & Bernard, 2021; Torii, 2024). Educational digitalization further supports learning that can be accessed anytime and anywhere, thereby expanding opportunities for independent and repeated learning (Simons & Crawford, 2021). In addition, artificial intelligence and digital authoring tools have accelerated the

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development of personalized learning materials, allowing educators to adjust content according to student needs and learning trajectories (Bricon-Souf & Przewozny, 2010). Evidence from digital education research indicates that technology integration can support students' cognitive ability when learning environments promote interaction, feedback, and meaningful engagement (Kong & Wang, 2024; Yan & Li, 2023).

More specifically, augmented reality (AR) offers substantial potential for strengthening mathematics learning because it provides visual, spatial, and interactive representations of abstract concepts. In digital learning environments, AR can transform static content into immersive learning experiences that encourage exploration and sustain student interest (Sahida et al., 2020). Prior studies have reported that AR-based media can increase learning interest, historical thinking, and conceptual understanding by enabling students to interact with virtual objects embedded in real or simulated contexts (Mursyidah et al., 2024; Safitri et al., 2023). In mathematics education, AR media have been developed for topics such as algebra and geometry, providing alternative representations that may help learners interpret formal concepts more concretely (Putri et al., 2025). Assemblr Edu is relevant because it facilitates the creation and use of three-dimensional and AR-based educational content, including ready-to-use topics, 3D libraries, virtual classrooms, custom AR markers, and editable learning projects (Américo da Silva et al., 2024; Baiti et al., 2024; Chairudin et al., 2023; Sahida et al., 2020). Studies using Assemblr Edu have also shown its value in promoting writing inspiration and improving argumentation, perseverance, and curiosity (Carrión-Robles et al., 2023; Kurniawan & Octavia, 2024).

The instructional potential of Assemblr Edu can be further strengthened when combined with the Multi-Entry Multi-Exit (MEME) approach. MEME is a flexible learning system that allows students to enter, continue, and complete learning activities according to their readiness, pace, and competency achievement, resembling modular and credit-based curriculum systems in higher education (Karlina & Muali, 2025; Putri et al., 2024; Yao et al., 2025). This flexibility is aligned with microlearning because both emphasize modular access, learner autonomy, and progression through manageable learning units. MEME also supports differentiated learning because students can revisit materials, complete activities according to cognitive readiness, and move to subsequent tasks after demonstrating sufficient understanding (Buduru & Pal, 2010). Such an approach is useful for prospective elementary school teachers, who must master mathematical concepts while learning how to represent them pedagogically for young learners. When Assemblr Edu, microlearning, and MEME are integrated, students may experience a concise, visually rich, flexible, and cognitively oriented learning environment.

The literature provides foundations for this integration, but several gaps remain. Studies on AR and Assemblr Edu have mainly emphasized learning interest, engagement, writing, argumentation, curiosity, or general conceptual understanding (Carrión-Robles et al., 2023; Kurniawan & Octavia, 2024; Safitri et al., 2023). Other studies have examined cognitive ability in relation to motivation, self-control, online learning, neurofeedback, adaptive feedback, and assessment models (Fu et al., 2025; Jamil et al., 2023; Ketova & Stolbova, 2024; Niu & Xue, 2023; Shi & Qu, 2021). Research in mathematics education has also explored difficulties in developing understanding of transformation geometry and the relationship between cognitive ability and learning interest (Hosler, 2025; Tarsinih & Juidah, 2021). Nevertheless, limited empirical evidence has examined the combined effect of microlearning, Assemblr Edu, and MEME on the cognitive abilities of preservice elementary school teachers in a mathematics education course. This gap is significant because teacher candidates require models that support conceptual mastery, flexible engagement, and pedagogical imagination.

The novelty of this study lies in positioning Assemblr Edu not merely as a digital visualization tool but as part of an integrated MEME-based microlearning model designed to enhance cognitive performance in mathematics education. The underlying hypothesis is that students who learn through MEME-based Assemblr Edu microlearning will demonstrate better cognitive outcomes than students who learn through conventional instruction because the model offers short learning units, AR-supported visualization, flexible entry and completion pathways, and repeated problem-solving opportunities. This study focuses on third-semester students in the Elementary School Teacher Education Program at STKIP Muhammadiyah Blora within a Mathematics Education course. The scope is limited to examining students' cognitive abilities as measured through learning outcome tests, rather than affective or psychomotor outcomes. Thus, the study provides empirical evidence on whether a technology-enhanced, modular, and flexible learning model can improve mathematical cognition among preservice elementary teachers.

Accordingly, this study aims to determine the effect of MEME-based Assemblr Edu microlearning on students' cognitive abilities in Mathematics Education. The study seeks to answer two research questions. First, is there a significant difference in cognitive ability between students who learn through MEME-based Assemblr Edu microlearning and students who learn through conventional instruction? Second, how much improvement in cognitive ability is achieved by students in the experimental class compared with those in the control class? By answering these questions, the study contributes to the development of evidence-based digital pedagogy for mathematics teacher education and offers a practical model for integrating microlearning, augmented reality, and flexible learning pathways in higher education.

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LITERATUR REVIEW

The rapid development of digital learning has reshaped the orientation of higher education from content delivery toward flexible, personalized, and cognitively engaging learning experiences. This shift is particularly relevant for Generation Z and Alpha learners, who are accustomed to short-form digital content, interactive media, immediate feedback, and autonomous access to information. In this context, microlearning has emerged as a major pedagogical trend because it organizes learning materials into concise, focused, and easily accessible units that can reduce cognitive overload while supporting repeated engagement with essential concepts (Kohnke, 2024; Termansen et al., 2023). Previous studies have emphasized that microlearning is especially suitable for students who require flexible learning pathways and adaptive access to instructional content, particularly in technology-rich educational environments (Dahiya & Bernard, 2021; Olivier, 2021; Torii, 2024). Thus, microlearning is not merely a strategy for shortening learning materials but an instructional design approach that restructures how knowledge is accessed, processed, and reinforced.

The literature on digital learning also indicates that the effectiveness of technology-enhanced instruction depends on the alignment between technological affordances, pedagogical design, and learner characteristics. Digital education technology can support students' cognitive sustainability when learning environments provide meaningful interaction, structured guidance, and opportunities for active knowledge construction (Kong & Wang, 2024; Yan & Li, 2023). Similarly, student-centered pedagogy and professional learning support are associated with stronger cognitive learning outcomes, particularly when digital tools are integrated into coherent instructional systems rather than used as isolated media (Kong & Wang, 2024). Studies on online and technology-assisted learning further suggest that students' cognitive performance is influenced by self-regulation, learning states, feedback quality, and the degree to which instructional systems respond to individual learning needs (Fu et al., 2025; Ma et al., 2024; Wang & Chung, 2024). Therefore, the central issue in digital pedagogy is not whether technology is present, but whether it is pedagogically structured to stimulate cognition.

One important technological development in this field is augmented reality (AR), which enables learners to interact with three-dimensional digital objects embedded in real or simulated environments. AR has been widely discussed as a promising medium for improving visualization, learning interest, conceptual understanding, and engagement in abstract or spatially demanding topics (Mursyidah et al., 2024; Putri et al., 2025; Safitri et al., 2023). In mathematics education, AR is particularly relevant because many mathematical ideas require students to transform abstract symbols into visual, spatial, or concrete representations. The development of AR media for algebra and other mathematical concepts indicates that immersive visualization can support students in interpreting complex forms and relationships more meaningfully (Putri et al., 2025). However, the literature also shows that AR-based learning must be supported by clear instructional sequencing because visual interactivity alone does not automatically produce conceptual mastery. Its impact depends on task design, scaffolding, learner readiness, and the quality of cognitive engagement during learning.

Assemblr Edu represents one of the AR-based platforms increasingly used in education because it allows teachers and students to design, access, and manipulate three-dimensional learning objects. Previous research has shown that Assemblr Edu can support writing inspiration in distance learning contexts and improve argumentation skills, perseverance, and curiosity in science learning (Carrión-Robles et al., 2023; Kurniawan & Octavia, 2024). These findings demonstrate that Assemblr Edu has pedagogical potential beyond visual presentation; it may stimulate students' reasoning, creativity, persistence, and engagement when embedded in appropriate learning activities. In addition, AR-based interactive learning media have been found to increase students' interest in environmental education and strengthen historical thinking when combined with inquiry-oriented or problem-based strategies (Mursyidah et al., 2024; Safitri et al., 2023). Nevertheless, most prior studies have focused on affective outcomes, engagement, writing performance, or subject-specific understanding, while fewer studies have directly examined Assemblr Edu as part of a structured microlearning model aimed at improving cognitive ability in mathematics teacher education.

The concept of cognitive ability occupies a central position in educational research because it reflects students' capacity to process information, understand concepts, reason logically, solve problems, and transfer knowledge across contexts. Cognitive ability is closely associated with academic achievement, motivation, self-regulated learning, and problem-solving performance (Asare et al., 2025; Lavrijsen et al., 2021; Preckel & Scherrer, 2025; Wang & Chung, 2024). Research has also shown that cognitive ability interacts with factors such as self-control, parental involvement, learning plans, teacher support, and learning attitudes, indicating that cognition develops through both individual and environmental mechanisms (Shi & Qu, 2021; Shi & Yang, 2025; Yang et al., 2024; Ye & Wang, 2024). In mathematics learning, cognitive ability is especially important because students must comprehend abstract structures, identify relationships, apply procedures, evaluate solutions, and construct mathematical meaning. For preservice elementary school teachers, this ability is even more critical because they are expected not only to understand mathematics but also to transform mathematical ideas into teachable representations for young learners.

Prior studies have examined various approaches to enhancing cognitive ability through digital modules, virtual laboratories, computer software, metaverse platforms, neurofeedback,

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adaptive feedback, and artificial intelligence-supported assessment systems (Afreen et al., 2024; Fu et al., 2025; Jamil et al., 2023; Johnson et al., 2021; Prasetya et al., 2023; Sunarno & Supriyanto, 2021). These studies generally indicate that technology can contribute to cognitive development when students are actively involved in inquiry, simulation, feedback, or interactive problem solving. For example, virtual laboratories and metaverse-based platforms have been reported to improve cognitive ability and practical skills, while adaptive feedback systems support cognitive development by responding to learners' performance patterns (Fu et al., 2025; Prasetya et al., 2023). However, the literature remains inconclusive regarding which instructional structures best support cognitive improvement. Some studies emphasize media interactivity, whereas others highlight feedback, self-regulation, learning motivation, or assessment design. This suggests that a more integrated pedagogical model is needed to connect media affordances with flexible learning progression and measurable cognitive outcomes.

The Multi-Entry Multi-Exit (MEME) approach provides a relevant pedagogical framework for such integration because it supports flexible learning progression based on students' readiness, pace, and competency achievement. MEME is conceptually aligned with modular learning and credit-based curriculum systems because it allows learners to enter, continue, revisit, and complete learning activities through flexible pathways (Buduru & Pal, 2010; Karlina & Muali, 2025; Putri et al., 2024; Yao et al., 2025). When connected with microlearning, MEME can help students engage with compact instructional units according to their individual learning needs. This approach is particularly appropriate for mathematics education because students often demonstrate different levels of prior knowledge, abstraction ability, and problem-solving readiness. Through MEME-based microlearning, students can revisit difficult concepts, proceed after achieving mastery, and engage with learning tasks in a more autonomous yet structured manner.

Despite these developments, several issues remain unclear in the existing literature. First, studies on microlearning have largely emphasized flexibility, engagement, and accessibility, but have not sufficiently examined how microlearning affects cognitive ability when combined with AR-based learning media. Second, studies on Assemblr Edu and AR have commonly focused on interest, motivation, writing, curiosity, or conceptual visualization, while empirical evidence on their effect on cognitive ability in mathematics education remains limited (Carrión-Robles et al., 2023; Kurniawan & Octavia, 2024; Putri et al., 2025; Safitri et al., 2023). Third, research on cognitive ability has examined many influencing factors, including motivation, self-regulation, feedback, teacher support, and digital technology, but relatively few studies have tested an instructional model that integrates microlearning, AR visualization, and flexible MEME pathways in one coherent intervention (Asare et al., 2025; Fu et al., 2025; Kong & Wang, 2024; Wang &

Chung, 2024). Therefore, the specific gap addressed in this study is the lack of quasi-experimental evidence on whether MEME-based Assemblr Edu microlearning can significantly improve the cognitive abilities of preservice elementary school teachers in a Mathematics Education course.

This study is positioned to address that gap by integrating three complementary elements: microlearning as a concise and modular instructional design, Assemblr Edu as an AR-supported visualization platform, and MEME as a flexible learning pathway. Unlike previous studies that treated AR primarily as a media innovation or examined cognitive ability as an isolated learner characteristic, this study conceptualizes cognitive improvement as the result of interaction between digital visualization, modular content, and flexible progression. The study therefore differs from prior research by testing an integrated instructional model in the specific context of mathematics teacher education. This position is important because preservice elementary teachers require not only digital learning experiences but also cognitively meaningful models that can strengthen mathematical understanding and later inform their pedagogical practice. Consequently, the present study contributes empirical evidence on the effectiveness of MEME-based Assemblr Edu microlearning as a structured digital pedagogy for improving students' cognitive abilities in Mathematics Education.

RESEARCH METHODS

This study employed a quantitative research approach with a quasi-experimental method to examine the effect of MEME-based Assemblr Edu microlearning on students' cognitive abilities in a Mathematics Education course. A quasi-experimental design was selected because the study was conducted in naturally formed university classes, making full random assignment of participants impractical. This design is appropriate for educational intervention studies because it allows researchers to compare learning outcomes between groups that receive different instructional treatments while maintaining the authentic structure of classroom learning (Malik et al., 2024; Zulhelmi, 2021). In line with the increasing use of digital learning interventions in higher education, this method enabled the study to evaluate whether a structured technology-supported learning model could produce measurable differences in students' cognitive performance. The design used in this study was a non-equivalent pretest-posttest control group design. This design was considered more suitable than a posttest-only design because it allowed the researcher to compare students' cognitive ability before and after the intervention and to determine the degree of improvement achieved by each group.

The study was conducted in the Elementary School Teacher Education Program at STKIP Muhammadiyah Blora. The research subjects were third-semester students enrolled in the Mathematics Education course. The population consisted of two intact classes, namely class 3A

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and class 3B, with a total of 68 students. A saturated sampling technique was applied because all members of the population were included as research participants. Class 3A, consisting of 35 students, was assigned as the experimental class, whereas class 3B, consisting of 33 students, was assigned as the control class. The use of intact classes was aligned with the quasi-experimental nature of the study, in which educational interventions are commonly implemented in existing learning groups rather than individually randomized settings (Malik et al., 2024; Zulhelmi, 2021). The experimental class received microlearning activities supported by the Assemblr Edu application and structured through the Multi-Entry Multi-Exit approach, while the control class received conventional instruction through lecture and discussion methods.

The independent variable in this study was the implementation of MEME-based Assemblr Edu microlearning, while the dependent variable was students' cognitive ability in Mathematics Education. The intervention was designed by integrating three instructional elements. First, microlearning was used to organize mathematical learning content into short, focused, and manageable units, consistent with previous literature indicating that microlearning supports flexible access, repeated engagement, and efficient processing of learning materials (Kohnke, 2024; Olivier, 2021; Termansen et al., 2023). Second, Assemblr Edu was used as an augmented reality-supported learning platform that enabled students to interact with visual and three-dimensional learning objects. Previous studies have shown that Assemblr Edu and augmented reality-based learning media can support student engagement, argumentation, curiosity, and conceptual visualization when integrated into structured learning activities (Carrión-Robles et al., 2023; Kurniawan & Octavia, 2024; Safitri et al., 2023). Third, the Multi-Entry Multi-Exit approach was applied to provide flexibility in learning progression, allowing students to access, revisit, and complete learning units according to their readiness and learning achievement (Buduru & Pal, 2010; Karlina & Muali, 2025; Putri et al., 2024; Yao et al., 2025).

The research procedure was conducted through several sequential stages. In the preparation stage, the researcher identified the learning outcomes of the Mathematics Education course, selected relevant mathematical topics, designed microlearning materials, and developed Assemblr Edu-based learning media. The instructional materials were prepared in compact learning units that included visual explanations, three-dimensional representations, brief conceptual summaries, and practice tasks. This structure was intended to help students process mathematical concepts through focused learning experiences while reducing unnecessary cognitive load. The cognitive orientation of the intervention was based on the view that cognitive ability involves understanding, information processing, logical reasoning, problem solving, and the transfer of knowledge across contexts (Asare et al., 2025; Preckel & Scherrer, 2025; Wang & Chung, 2024).

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Therefore, the learning activities were designed not merely to present digital content but to stimulate students' conceptual understanding and reasoning in mathematics.

Before the intervention, both the experimental and control classes were given a pretest to measure their initial cognitive ability. The pretest was administered to establish baseline comparability between the two groups and to provide data for calculating learning improvement after the intervention. After the pretest, the experimental class participated in learning using MEME-based Assemblr Edu microlearning. In this class, students accessed short learning units through Assemblr Edu, observed and interacted with visual learning objects, completed guided activities, and revisited materials when needed before continuing to subsequent tasks. The MEME structure allowed students to engage with the learning process through flexible entry and completion points while remaining aligned with the course objectives. In contrast, the control class received conventional instruction using lecture and discussion methods. The same general mathematical topics were taught in both classes to ensure that differences in learning outcomes could be attributed primarily to the instructional treatment rather than to differences in content exposure.

The materials used in this study consisted of Mathematics Education learning content, Assemblr Edu-based microlearning media, lecturer-prepared teaching materials, and cognitive test instruments. The Assemblr Edu materials were designed to present mathematical concepts through concise explanations and interactive visual representations. This choice was supported by studies showing that digital modules, augmented reality, and interactive learning platforms may enhance cognitive learning when they provide students with opportunities to visualize, manipulate, and interpret learning content (Johnson et al., 2021; Prasetya et al., 2023; Sunarno & Supriyanto, 2021). The cognitive test instrument was constructed to measure students' ability to understand mathematical concepts, apply procedures, analyze problems, and draw logical conclusions. The test items were aligned with the course learning outcomes and the cognitive dimensions relevant to mathematics education.

Data collection was conducted using cognitive ability tests administered before and after the learning intervention. The pretest measured students' initial cognitive ability, while the posttest measured cognitive ability after the instructional treatment had been completed. The use of cognitive tests was consistent with prior studies emphasizing that cognitive ability can be assessed through tasks that require reasoning, conceptual processing, analytical thinking, and problem solving (Ketova & Stolbova, 2024; Visessuvanapoom & Wintachai, 2024). In addition to producing posttest scores, the pretest and posttest data were used to determine the level of cognitive improvement in each class. The research hypotheses were formulated as follows: the null hypothesis stated that MEME-based Assemblr Edu microlearning had no significant effect

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on students' cognitive abilities in Mathematics Education, while the alternative hypothesis stated that MEME-based Assemblr Edu microlearning had a significant effect on students' cognitive abilities in Mathematics Education.

The data analysis technique involved descriptive and inferential statistical procedures. Descriptive analysis was used to present the mean score, standard deviation, minimum score, and maximum score of students' cognitive ability in the experimental and control classes. Before hypothesis testing, prerequisite tests were conducted to determine whether the data met the assumptions for parametric analysis. The Liliefors test was used to examine data normality, while the F-test was used to determine the homogeneity of variance between the experimental and control groups. After the assumptions were satisfied, an independent-samples t-test was conducted to examine whether there was a significant difference in posttest scores between the two classes. In addition, normalized gain analysis was used to determine the magnitude of improvement in students' cognitive ability from pretest to posttest. This analysis was important because improvement scores provide a clearer indication of learning progress than posttest scores alone, particularly in studies involving educational interventions.

Data validity was maintained through content validation, procedural consistency, and statistical assumption testing. The cognitive test instrument was reviewed to ensure that each item corresponded to the intended course outcomes and cognitive indicators. The learning materials used in the experimental and control classes were aligned with the same Mathematics Education topics to maintain content equivalence across groups. The intervention procedures were implemented consistently according to the research design, with the experimental class receiving MEME-based Assemblr Edu microlearning and the control class receiving conventional instruction. Statistical validity was strengthened through normality and homogeneity testing before conducting the t-test. These procedures ensured that the conclusions drawn from the data were based on appropriate analytical assumptions and that the observed differences in cognitive ability reflected the effect of the instructional intervention. Thus, the methodological design provided a systematic basis for evaluating the influence of MEME-based Assemblr Edu microlearning on students' cognitive abilities in Mathematics Education.

RESULT

The results of this study indicate that MEME-based Assemblr Edu microlearning produced a measurable positive effect on students' cognitive abilities in the Mathematics Education course. The analysis was conducted by comparing the pretest and posttest scores of the experimental class, which received microlearning through the Assemblr Edu application based on the Multi-Entry Multi-Exit approach, and the control class, which received conventional instruction through lecture and discussion methods. This comparison is important because cognitive ability reflects students' capacity to understand concepts, process information, apply procedures, analyze problems, and construct logical conclusions in academic learning contexts (Asare et al., 2025; Preckel & Scherrer, 2025; Wang & Chung, 2024). The findings demonstrate that both classes experienced improvement after the learning process, but the increase in the experimental class was higher than that of the control class. This result suggests that the integration of microlearning, augmented reality-based learning media, and flexible learning pathways provided stronger support for students' cognitive development than conventional classroom instruction.

Table 1. Descriptive statistics of students' cognitive ability scores

Class	N	Pretest Mean	Posttest Mean	Posttest SD	Mean Difference	N-Gain
Experimental class	35	54.70	78.22	9.03	23.52	0.51
Control class	33	53.89	68.41	11.82	14.52	0.31

As shown in Table 1, the initial cognitive ability of students in the experimental and control classes was relatively comparable. The experimental class obtained a pretest mean score of 54.70, while the control class obtained a pretest mean score of 53.89. The small difference between the two pretest means indicates that the two groups began the intervention from a relatively similar level of cognitive readiness. This baseline comparability is essential in quasi-experimental research because naturally formed classroom groups cannot be fully randomized, and the validity of the intervention effect depends partly on whether the initial conditions of the two groups are sufficiently similar (Malik et al., 2024; Zulhelmi, 2021). The pretest results therefore provide an empirical basis for interpreting the posttest difference as a result that is plausibly associated with the instructional treatment.

After the intervention, the experimental class obtained a posttest mean score of 78.22 with a standard deviation of 9.03, whereas the control class obtained a posttest mean score of 68.41 with a standard deviation of 11.82. The mean difference between the pretest and posttest scores in the experimental class was 23.52 points, while the mean difference in the control class was 14.52 points. This indicates that students who learned through MEME-based Assemblr Edu microlearning achieved greater cognitive improvement than students who learned through lecture and discussion. The lower posttest standard deviation in the experimental class also suggests that student performance became more consistent after the intervention. This pattern may indicate that the digital and modular learning environment helped reduce performance gaps among students by allowing repeated access to learning content, flexible progression, and visual support. Such a finding is consistent with the view that microlearning can support learning efficiency by dividing

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content into concise units that students can revisit according to their needs (Kohnke, 2024; Olivier, 2021; Termansen et al., 2023).

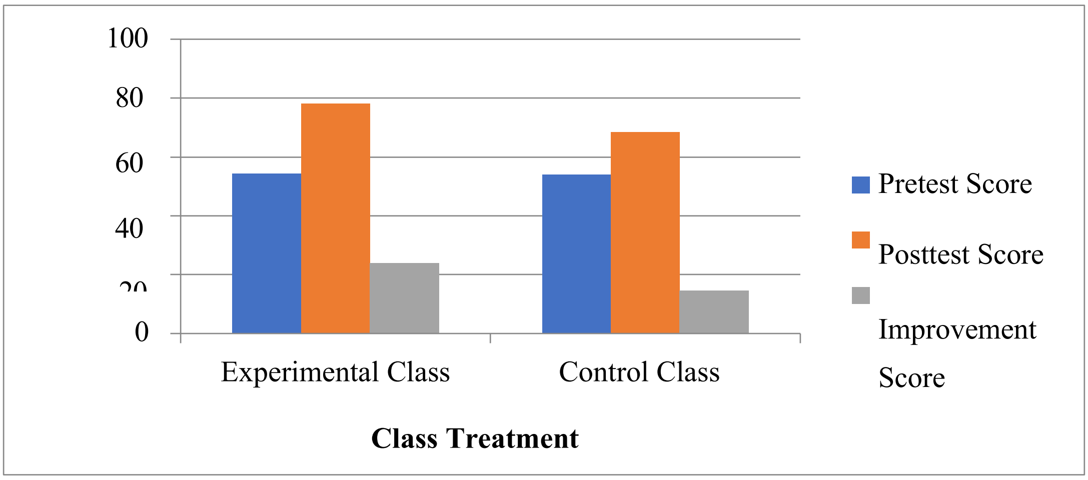

Figure 1. Comparison of mean pretest and posttest scores between the experimental and control classes

Figure 1 illustrates that the experimental class and the control class started from nearly equivalent pretest scores but showed different levels of posttest achievement. The experimental class showed a steeper increase from pretest to posttest, indicating stronger learning gains after exposure to MEME-based Assemblr Edu microlearning. The visual comparison supports the descriptive statistical result in Table 1 by showing that the intervention did not merely produce a higher final score but also resulted in a greater degree of improvement. This result is relevant to literature emphasizing that technology-enhanced learning is most effective when digital tools are embedded in structured pedagogical activities rather than used only as supplementary media (Kong & Wang, 2024; Yan & Li, 2023). In this study, Assemblr Edu functioned not only as a presentation tool but also as a medium for interactive visualization, while the MEME approach provided a flexible pathway for students to access and complete learning activities.

Before hypothesis testing was conducted, prerequisite statistical tests were performed to determine whether the data met the assumptions required for parametric analysis. Normality testing was carried out using the Liliefors test for the pretest and posttest scores of both classes. The results showed that the calculated L values were lower than the critical L values, indicating that the data from both the experimental and control classes were normally distributed. Homogeneity testing was then conducted using the F-test to determine whether the variances of the two groups were homogeneous. These tests were necessary because the independent-samples t-test requires that the data approximate normal distribution and that the two groups have comparable variance. The results of the prerequisite tests are presented in Table 2.

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Table 2. Results of normality and homogeneity tests

Statistical Test	Data Tested	Result	Interpretation
Liliefors normality test	Pretest and posttest scores	Lcalculated < Ltable	Normally distributed
F-test for homogeneity	Pretest scores	1.23 < 1.93	Homogeneous variance
F-test for homogeneity	Posttest scores	1.71 < 1.93	Homogeneous variance

Table 2 shows that the pretest and posttest data satisfied the assumptions of normality and homogeneity. The pretest homogeneity test produced Fcalculated = 1.23, which was lower than Ftable = 1.93. Similarly, the posttest homogeneity test produced Fcalculated = 1.71, which was also lower than Ftable = 1.93. These results indicate that the two groups had homogeneous variance at the 5% significance level. Therefore, the use of the independent-samples t-test was statistically appropriate. The fulfillment of these assumptions strengthens the reliability of the inferential analysis because the observed difference between the experimental and control classes was examined using data that met the required statistical conditions. This procedural consistency is important in intervention-based educational research, particularly when evaluating learning models designed to improve cognitive outcomes (Ketova & Stolbova, 2024; Visessuvanapoom & Wintachai, 2024).

The hypothesis test was conducted to determine whether the difference in posttest achievement between the experimental and control classes was statistically significant. The t-test result showed that tcalculated = 3.43, while ttable = 2.00 at the 5% significance level. Because tcalculated was greater than ttable, the null hypothesis was rejected and the alternative hypothesis was accepted. This means that there was a significant effect of MEME-based Assemblr Edu microlearning on students' cognitive abilities in the Mathematics Education course. The statistical result confirms that the higher posttest score in the experimental class was not merely descriptive but also inferentially significant. This finding supports the assumption that digital learning environments can enhance cognitive learning when they provide structured interaction, meaningful visual representation, and opportunities for active processing (Fu et al., 2025; Johnson et al., 2021; Prasetya et al., 2023; Sunarno & Supriyanto, 2021).

Table 3. Results of hypothesis testing and normalized gain analysis

Analysis	Experimental Class	Control Class	Statistical Result	Interpretation
Posttest mean	78.22	68.41	tcalculated = 3.43 > ttable = 2.00	Significant difference
N-Gain mean	0.51	0.31	Experimental class > Control class	Higher improvement in the experimental class

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Table 3 confirms that the experimental class outperformed the control class in both posttest achievement and normalized gain. The experimental class obtained an average N-Gain score of 0.51, while the control class obtained an average N-Gain score of 0.31. Both scores indicate improvement, but the experimental class achieved a higher level of cognitive gain. The N-Gain result is particularly important because it shows not only the final learning achievement but also the magnitude of progress from the initial condition. The stronger gain in the experimental class indicates that MEME-based Assemblr Edu microlearning was more effective in improving students' cognitive ability than conventional learning. This result aligns with prior studies indicating that students' cognitive development can be enhanced when learning environments integrate interactive digital media, feedback, visualization, and flexible access to learning resources (Afreen et al., 2024; Fu et al., 2025; Ma et al., 2024; Wang & Chung, 2024).

The higher cognitive improvement in the experimental class can be explained by the instructional characteristics of the treatment. Microlearning enabled students to learn mathematical content through shorter and more focused units, making the learning process more manageable. This structure is relevant to students who require flexible access to learning materials and opportunities to repeat content independently (Dahiya & Bernard, 2021; Kohnke, 2024; Olivier, 2021). At the same time, Assemblr Edu provided visual and interactive representations that helped students connect abstract mathematical concepts with more concrete learning objects. Previous research on augmented reality and Assemblr Edu has shown that these media can increase engagement, curiosity, and conceptual visualization because students interact with learning content in a more immersive and exploratory manner (Carrión-Robles et al., 2023; Kurniawan & Octavia, 2024; Putri et al., 2025; Safitri et al., 2023). In the present study, this interaction appears to have supported students' cognitive processing by helping them observe, interpret, and apply mathematical concepts more actively.

The Multi-Entry Multi-Exit structure also contributed to the learning gains observed in the experimental class. The MEME approach allowed students to enter, revisit, and complete learning activities based on their readiness and progress. This flexibility is pedagogically relevant because students in mathematics education often have different levels of prior knowledge and different speeds of conceptual understanding. The MEME approach therefore provided students with opportunities to regulate their learning pathway while still following the instructional objectives of the course. This result is consistent with literature describing MEME and modular learning systems as flexible approaches that support learner autonomy, progression, and competency-based completion (Buduru & Pal, 2010; Karlina & Muali, 2025; Putri et al., 2024; Yao et al., 2025). In the context of this study, flexible learning progression appears to have strengthened students' ability to engage with mathematical problems more accurately and independently.

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In contrast, the control class also showed improvement, but the increase was lower than that of the experimental class. The improvement in the control class indicates that lecture and discussion methods still supported learning to some extent, particularly because students were exposed to the same general mathematical topics. However, conventional instruction offered fewer opportunities for interactive visualization, repeated access to compact learning units, and flexible progression. As a result, the cognitive gains in the control class were more limited. This finding reinforces the argument that conventional learning may be less effective when students are required to master abstract concepts that benefit from visual representation and active exploration. Studies on digital education technology similarly suggest that students' cognitive learning is strengthened when instructional environments promote interaction, student-centered pedagogy, and meaningful engagement rather than relying solely on teacher-centered delivery (Kong & Wang, 2024; Yan & Li, 2023).

Overall, the results provide empirical evidence that MEME-based Assemblr Edu microlearning positively affects students' cognitive abilities in Mathematics Education. The experimental class demonstrated higher posttest achievement, greater mean improvement, and a stronger normalized gain than the control class. The acceptance of the alternative hypothesis confirms that the intervention significantly improved cognitive performance. These findings indicate that the integration of microlearning, Assemblr Edu, and the MEME approach can provide a cognitively supportive learning environment for preservice elementary school teachers. The results also show that students' accuracy in solving mathematical problems can be strengthened when they engage with learning materials through concise content, interactive visualization, and flexible learning pathways. Therefore, MEME-based Assemblr Edu microlearning can be considered an effective instructional model for enhancing cognitive ability in Mathematics Education.

DISCUSSION

The findings of this study demonstrate that MEME-based Assemblr Edu microlearning produced a stronger improvement in students' cognitive abilities than conventional lecture and discussion methods. As presented in Table 1, the experimental class achieved a higher posttest mean score than the control class, with scores of 78.22 and 68.41, respectively. The normalized gain analysis in Table 3 further indicates that the experimental class obtained a higher N-Gain score of 0.51, compared with 0.31 in the control class. These findings suggest that students who engaged with concise microlearning units, augmented reality-supported visualization, and flexible Multi-Entry Multi-Exit learning pathways were better able to process mathematical information, understand concepts, and apply procedures. This result is consistent with the view

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that cognitive ability is not merely a static individual attribute but can be strengthened through instructional environments that support reasoning, conceptual processing, and problem-solving activities (Asare et al., 2025; Preckel & Scherrer, 2025; Wang & Chung, 2024).

The difference between the experimental and control classes can be interpreted through cognitive learning theory, particularly the assumption that learning becomes more effective when information is organized into manageable units and presented through meaningful representations. Microlearning supports this principle because it divides complex instructional content into short, focused, and accessible segments that help students manage cognitive load during learning (Kohnke, 2024; Lopez, 2024; Olivier, 2021). In mathematics education, this structure is highly relevant because students often experience difficulty when abstract concepts are presented continuously through long explanations without sufficient opportunities for gradual processing. The improvement shown in the experimental class indicates that microlearning helped students focus on essential mathematical ideas, revisit difficult concepts, and regulate their own learning pace. This finding supports previous arguments that microlearning is not simply a shortened version of instruction but a pedagogical strategy that restructures learning into cognitively efficient and learner-centered experiences (Dahiya & Bernard, 2021; Termansen et al., 2023; Torii, 2024).

The results also support the theoretical position that visual and interactive representation can enhance students' understanding of abstract concepts. Assemblr Edu, as an augmented reality-based learning platform, enabled students to engage with mathematical materials through three-dimensional and interactive visual objects. Such visual affordances are particularly important in mathematics education because students need to connect symbolic procedures with conceptual meaning and spatial representation. Prior studies have shown that augmented reality-based media can increase learning interest, strengthen conceptual visualization, and support students' active interaction with learning content (Mursyidah et al., 2024; Putri et al., 2025; Safitri et al., 2023). The higher cognitive achievement in the experimental class therefore indicates that Assemblr Edu may have helped students construct clearer mental representations of mathematical concepts. This finding is also aligned with studies showing that Assemblr Edu can improve argumentation, curiosity, perseverance, and learning inspiration when used in structured learning environments (Carrión-Robles et al., 2023; Kurniawan & Octavia, 2024).

However, the findings should not be interpreted as evidence that technology alone improves cognitive ability. The stronger performance of the experimental class is more plausibly explained by the integration of technology with a coherent instructional design. Digital tools become pedagogically meaningful when they are combined with structured learning activities, feedback, and student-centered engagement (Kong & Wang, 2024; Yan & Li, 2023). In this study, Assemblr Edu functioned not only as a visual medium but also as part of a broader microlearning and MEME-based system. The learning materials were presented in concise units, students were allowed to revisit learning content, and learning progression was adjusted through flexible entry and completion pathways. This interpretation is consistent with prior research indicating that technology-enhanced learning contributes to cognitive development when students are actively involved in inquiry, simulation, feedback, and repeated problem solving (Fu et al., 2025; Johnson et al., 2021; Prasetya et al., 2023; Sunarno & Supriyanto, 2021).

The Multi-Entry Multi-Exit approach appears to be a critical element in explaining the improvement obtained by the experimental class. Mathematics learners often differ in prior knowledge, learning speed, conceptual readiness, and confidence in solving problems. A conventional classroom model tends to move students through the same sequence and pace, even when some students require more time to understand particular concepts. In contrast, MEME provides a flexible learning structure that allows students to access, revisit, and complete learning activities according to their readiness and achievement. This approach is compatible with modular and competency-based learning because students can progress through learning units after demonstrating adequate understanding (Buduru & Pal, 2010; Karlina & Muali, 2025; Putri et al., 2024; Yao et al., 2025). The greater N-Gain score in the experimental class suggests that flexibility in learning progression helped students build cognitive competence more effectively than a uniform instructional pathway.

The findings are also relevant to discussions on the learning characteristics of Generation Z and Alpha students. These learners are commonly associated with frequent exposure to digital content, preference for interactive media, and demand for flexible access to learning resources (Jain, 2025; Labibah, 2025; Raslie & Ting, 2021; Widiayanti et al., 2022). Nevertheless, generational preferences should not be understood as a justification for superficial or entertainment-oriented learning. The present findings indicate that digital learning is effective when it is academically structured, cognitively purposeful, and aligned with measurable learning outcomes. The use of MEME-based Assemblr Edu microlearning responded to students' digital learning habits while maintaining rigorous academic expectations. Therefore, the author's position is that digital pedagogy in higher education should integrate flexibility and interactivity with disciplined conceptual development, rather than replacing academic depth with technological novelty.

The improvement in the experimental class also confirms the importance of active cognitive engagement in mathematics learning. Mathematics education requires more than memorizing formulas or following procedures. Students must interpret problems, connect prior knowledge, select appropriate strategies, evaluate solution steps, and explain reasoning. These

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activities are closely related to cognitive ability, which includes information processing, logical reasoning, concept formation, and problem solving (Clemente et al., 2024; Ernest et al., 2016; Mamolo, 2022; Situmorang, 2018). Through Assemblr Edu, students were exposed to visual materials that encouraged observation and interpretation. Through microlearning, they received smaller units of content that were easier to process. Through MEME, they had opportunities to revisit learning tasks and proceed according to their understanding. The combination of these elements likely strengthened students' accuracy and confidence in solving mathematical problems.

Compared with previous studies, this research extends the literature by showing that Assemblr Edu can be used not only to improve engagement, writing inspiration, curiosity, or argumentation but also to enhance cognitive ability in mathematics teacher education. Carrión-Robles et al. (2023) demonstrated the usefulness of Assemblr Edu for supporting writing in a distance learning context, while Kurniawan and Octavia (2024) showed its contribution to argumentation skills, perseverance, and curiosity in physics learning. The present study differs from those studies by applying Assemblr Edu within a MEME-based microlearning framework and evaluating its effect on cognitive outcomes among preservice elementary school teachers. This distinction is important because cognitive ability in mathematics has direct implications for teacher preparation. Preservice teachers who develop stronger conceptual understanding are more likely to design meaningful representations and explanations for elementary students.

The result also complements studies on cognitive ability in digital and online learning environments. Research by Fu et al. (2025) emphasized the role of adaptive feedback in improving cognitive ability, while Wang and Chung (2024) highlighted the relationship between cognitive ability and self-regulated learning in online contexts. Similarly, studies on digital modules, virtual laboratories, and metaverse-based learning have shown that interactive environments can strengthen cognitive outcomes when students are required to engage with content actively (Prasetya et al., 2023; Sunarno & Supriyanto, 2021). The present study contributes to this body of research by demonstrating that cognitive improvement can also be supported through the integration of short learning units, augmented reality visualization, and flexible progression. Unlike approaches that rely primarily on feedback systems or virtual laboratories, the model in this study emphasizes accessibility, visual clarity, and learner-controlled pathways within a mathematics education course.

The lower improvement in the control class does not imply that lecture and discussion methods are ineffective. The control class also demonstrated learning progress, indicating that conventional instruction can support students' cognitive development when the content is delivered appropriately. However, the smaller gain suggests that lecture and discussion may

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provide limited support for students who require visual mediation, flexible pacing, and repeated access to mathematical materials. This is particularly relevant for abstract mathematical topics that require students to transform symbolic information into conceptual understanding. The difference shown in Figure 1 indicates that both groups began from relatively similar pretest conditions but diverged after the intervention. This pattern strengthens the argument that the instructional model, rather than initial ability, contributed to the stronger performance of the experimental class.

From a practical perspective, the findings suggest that lecturers in mathematics teacher education should consider integrating microlearning and augmented reality into course design, particularly for topics that require visualization and gradual conceptual development. The implementation should begin with clear learning outcomes, followed by the development of concise learning units, interactive visual materials, formative exercises, and flexible access mechanisms. Assemblr Edu can be used to create learning objects that help students observe mathematical relationships, while MEME can organize learning progression so that students have sufficient time to master each unit before moving forward. This solution is relevant for institutions seeking to improve cognitive learning outcomes without replacing the role of lecturers. Lecturers remain central as designers, facilitators, evaluators, and providers of conceptual guidance.

The author's position is that MEME-based Assemblr Edu microlearning should be understood as a pedagogical system rather than a single media innovation. Its effectiveness depends on the alignment between content structure, technological representation, learner autonomy, and assessment of cognitive progress. Institutions that intend to adopt this model should provide lecturer training, technical support, and quality assurance for digital learning materials. Further classroom implementation should also include monitoring of students' learning behavior, feedback patterns, and difficulties during independent access to microlearning content. Such implementation can help prevent technology use from becoming fragmented and ensure that augmented reality, microlearning, and flexible progression remain directed toward deeper mathematical understanding.

CONCLUSION

This study concludes that MEME-based Assemblr Edu microlearning is an effective instructional approach for improving students' cognitive abilities in Mathematics Education. The main finding indicates that students who learned through the integration of microlearning, augmented reality-based visualization, and flexible Multi-Entry Multi-Exit learning pathways achieved stronger cognitive performance than those who experienced conventional lecture and discussion methods. The higher posttest achievement and normalized gain in the experimental

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class demonstrate that concise learning units, interactive digital representations, and flexible access to learning content can support students in understanding, processing, and applying mathematical concepts more effectively.

The findings imply that digital learning innovation should not be limited to the use of technology as a presentation medium but should be designed as a structured pedagogical system that promotes active cognitive engagement. In this regard, the study contributes to the existing body of knowledge by providing empirical evidence on the combined use of microlearning, Assemblr Edu, and MEME in mathematics teacher education. This integrated model offers a practical alternative for preparing preservice elementary school teachers to engage with mathematical content through more adaptive, visual, and student-centered learning experiences.

Future research should examine the long-term impact of MEME-based Assemblr Edu microlearning on higher-order thinking skills, mathematical problem-solving, learning motivation, and teaching readiness. Further studies may also involve larger samples, multiple institutions, different mathematical topics, and mixed-method designs to obtain broader and deeper evidence of its pedagogical effectiveness.

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