

ENHANCING TEACHERS' DIGITAL COMPETENCE THROUGH GENERATIVE AI-BASED 3D CARTOON LEARNING MEDIA FOR DEEP LEARNING

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Abstract. The rapid development of Generative Artificial Intelligence (GenAI) provides new opportunities for teachers to create innovative digital learning resources. Still, its educational value depends on teachers' digital competence and pedagogical ability to use AI appropriately. This study aimed to examine the development of teachers' Generative AI competence through the development of 3D cartoon learning media aligned with the principles of Mindful, Meaningful, and Joyful Learning. A mixed-method intervention design was employed with 130 elementary school teachers from the Gugus Dewi Kunthi elementary school cluster in Gunungpati, Semarang, Indonesia. The quantitative component used a one-group pretest–posttest design, while qualitative data were collected through observation, documentation, mentoring activities, and analysis of teacher-produced learning-media products. The intervention consisted of orientation and initial assessment, Generative AI training, 3D cartoon media production, mentoring and pedagogical integration, and evaluation. The results showed that Generative AI literacy increased from 10% to 100%, while the utilization of Generative AI for learning-media development increased from 10% to 98%. The 130 participating teachers also produced 130 3D cartoon learning media products. Product analysis indicated the integration of visual storytelling, animation, narration, contextual content, and the principles of Mindful, Meaningful, and Joyful Learning. The findings suggest that practice-based Generative AI professional development can support teachers in moving from digital content users to learning-media creators and pedagogical decision-makers. However, given the absence of a comparison group and direct measures of student learning outcomes, the findings do not establish causal effects on student achievement. Generative AI can therefore serve as an enabling technology to strengthen teachers' capacity to create contextual and pedagogically oriented digital learning resources while maintaining teacher agency at the center of the learning process.

Keywords: Generative Artificial Intelligence; Teacher Digital Competence; 3D Cartoon Learning Media; Deep Learning; Elementary Education; Teacher Professional Development

INTRODUCTION

The rapid development of digital technologies and artificial intelligence (AI) is transforming the way teaching and learning are designed, delivered, and experienced. In primary education, this transformation creates opportunities for teachers to develop learning environments that are more visual, interactive, contextual, and responsive to students' learning needs. Generative Artificial Intelligence (GenAI), in particular, provides teachers with new possibilities to create text, images, animations, audio, and video for educational purposes. However, the educational value of GenAI depends not simply on access to technological tools but on teachers' ability to use them

appropriately, ethically, and pedagogically. Miao and Holmes (2023) emphasize that a human-centered approach, ethical considerations, data privacy, and appropriate pedagogical design should guide the use of GenAI in education. Recent research similarly suggests that integrating AI into education requires attention to teachers' preparedness, professional learning, and the conditions that shape their adoption of AI-supported practices (Panday-Shukla, 2025; Yuan et al., 2026).

The increasing use of AI in education consequently requires teachers to develop competencies that extend beyond basic technological skills. Miao and Cukurova (2024) conceptualize AI competency for teachers through five dimensions: human-centered mindset, ethics of AI, AI foundations and applications, AI pedagogy, and AI for professional learning. These dimensions indicate that teachers need not only to operate AI tools but also to understand their pedagogical possibilities, ethical implications, and appropriate application in teaching and learning. This perspective is supported by Sperling et al. (2024), whose scoping review highlights the growing importance of AI literacy in teacher education and identifies gaps in teachers' practical and ethical knowledge. Daher (2025) likewise argues that AI literacy in teacher education should extend beyond technical skills to include an understanding of AI mechanisms, applications, and ethical implications. Ng et al. (2023) further emphasize that teachers require adequate AI-related digital competencies to use AI educational applications effectively and to support students' development of AI-related capabilities.

This perspective is consistent with the broader concept of teachers' digital competence. Claro et al. (2024), through a systematic review of quantitative studies, demonstrate that teachers' digital competence encompasses the ability to plan digital learning, integrate technology into teaching, facilitate students' digital activities, and develop learners' twenty-first-century skills. Similarly, Wohlfart and Wagner (2023) emphasize the central role of teachers in the digital transformation of education, noting that integrating technology requires changes in teachers' professional roles and pedagogical practices. Thus, AI integration should be understood not simply as the acquisition of new technical skills but as a process of professional development involving pedagogical judgment, instructional design, ethical awareness, and changes in teachers' roles.

In primary education, the development of engaging and concrete learning media is particularly important because elementary school students often require visual and contextual representations to understand abstract concepts. Animated and audiovisual media can provide such representations by combining visual elements, narration, characters, movement, and contextual situations. Fitriani et al. (2025), for example, reported that the use of animated cartoon audiovisual media was associated with increased motivation to learn among third-grade elementary school students. Similarly, Tiku et al. (2026) examined animated video-based learning media in Indonesian language instruction and reported its contribution to improving the motivation to learn of fourth-grade elementary school students. These findings indicate that animation can serve not merely as a decorative element but as a pedagogically designed medium for supporting students' attention and learning experiences.

The emergence of GenAI provides further opportunities for teachers to develop such media more efficiently and creatively. Yuan et al. (2026), in their systematic review of GenAI in teacher education, identified instructional resource generation and curriculum design among the major application areas of GenAI. Their review also highlights the limited empirical and longitudinal evidence currently available and calls for more rigorous, inclusive, and context-sensitive research on GenAI in teacher education. Panday-Shukla (2025), based on an exploratory study of pre-service teachers and teacher educators, similarly reported that AI literacy remained relatively low despite generally positive interest in GenAI, underscoring the need for professional development

opportunities. Therefore, the use of GenAI to produce 3D cartoon learning media should not be understood simply as a technical process for generating images or videos. Rather, it should involve teachers' ability to translate curriculum objectives into meaningful stories, characters, visual scenes, narration, and learning activities.

This perspective is particularly relevant to the concept of deep learning promoted in Indonesian education. The Ministry of Primary and Secondary Education of the Republic of Indonesia conceptualizes *Pembelajaran Mendalam* (Deep Learning) through the principles of Mindful, Meaningful, and Joyful Learning. The approach emphasizes learning experiences that are conscious, meaningful, and enjoyable, with students positioned at the center of the learning process. The Ministry further emphasizes that deep learning should create concrete and meaningful learning experiences that support students' deeper understanding and active engagement (Kementerian Pendidikan Dasar dan Menengah, 2025, 2026). The 2026 policy communication further reinforces that Mindful, Meaningful, and Joyful principles are central to the implementation of *Pembelajaran Mendalam*.

Within this framework, 3D cartoon learning media generated with the assistance of GenAI can provide teachers with a practical means of translating curriculum content into visual and contextual learning experiences. The Mindful dimension can be supported through focused visual narratives and structured sequences that direct students' attention to key concepts. The Meaningful dimension can be strengthened by presenting learning content through familiar contexts, characters, and situations that connect with students' prior experiences. Meanwhile, the Joyful dimension can be encouraged through engaging characters, animation, narration, and visually attractive storytelling. Nevertheless, animation or GenAI technology alone does not automatically constitute deep learning. The pedagogical value of the media remains dependent on teachers' instructional decisions, learning objectives, contextualization, and the activities designed around the media. This distinction is consistent with the broader literature emphasizing that AI literacy involves not only technological knowledge but also practical, pedagogical, and ethical knowledge (Sperling et al., 2024; Daher, 2025).

The context of the partner schools demonstrates the need for such capacity development. The participating teachers had relatively strong experience with conventional digital presentation tools, particularly PowerPoint, while their use of interactive, contextual, and GenAI-supported learning media remained limited. Approximately 85% of teachers reported using PowerPoint, while around 60% relied on passive learning videos. At the same time, approximately 95% had not yet used Generative AI to develop interactive and contextual learning media, particularly 3D cartoon-based resources. This situation suggests a gap between teachers' current use of digital technology and the more advanced competencies required to design, produce, and pedagogically integrate AI-supported learning resources. Such a gap is consistent with research showing that teachers may possess general digital competence while still requiring additional AI-specific knowledge and professional learning (Ng et al., 2023; Sperling et al., 2024; Panday-Shukla, 2025).

The challenge is therefore not merely to introduce teachers to new AI tools but to strengthen their capacity to create learning media. Miao and Cukurova (2024) emphasize that teachers' AI competence involves knowledge, skills, values, and pedagogical application, while Miao and Holmes (2023) highlight the importance of human agency and responsible use of GenAI. Daher (2025) similarly argues that effective AI literacy development requires professional learning that moves beyond technical operation toward understanding AI applications and ethical implications. In addition, Lan (2024) demonstrates that AI-enhanced teacher training can involve tensions concerning professional identity and the relationship between human expertise and technology.

These perspectives reinforce the importance of positioning teachers as primary pedagogical decision-makers, while GenAI functions as an enabling technology that supports the creative production process. This orientation also corresponds with Yuan et al. (2026), who identify instructional resource generation and curriculum design as important areas of GenAI application in teacher education.

Based on this background, the present study focuses on strengthening teachers' digital competence by developing Generative AI-based 3D cartoon learning media for deep learning. The intervention was designed to move teachers from primarily consuming or presenting digital content toward designing and producing their own contextual learning resources. Through training, guided production, mentoring, and pedagogical integration, teachers were encouraged to develop 3D cartoon learning media that reflect the principles of Mindful, Meaningful, and Joyful Learning. The study, therefore, examines the initial level of teachers' Generative AI competence, the improvement in their ability to design and produce digital learning resources, and the potential of the resulting 3D cartoon media to support deep-learning-oriented practices in elementary education.

METHODS

Research Design

This study employed a mixed-method intervention design to examine the development of teachers' digital competence through Generative AI-based 3D cartoon learning media. A mixed-methods approach was selected because the study sought to examine both measurable changes in teachers' competence and qualitative evidence of their experiences, practices, and learning media products (Creswell & Plano Clark, 2017). The quantitative component used a one-group pretest–posttest design to assess changes in teachers' Generative AI literacy and their ability to use Generative AI to develop learning media. The qualitative component was used to document the training process, teachers' experiences, media production practices, and the characteristics of the learning media products developed during the program.

The study was designed around an authentic professional development process in which teachers were not merely introduced to Generative AI tools but guided to apply them to develop learning resources. This orientation is consistent with Miao and Cukurova's (2024) AI Competency Framework for Teachers, which emphasizes the development of teachers' knowledge, skills, values, AI pedagogy, and professional learning. The intervention consisted of orientation and initial assessment, Generative AI training, 3D cartoon media production, mentoring and pedagogical integration, and evaluation and sustainability activities. This design allowed the study to examine both measurable changes in teachers' competence and the practical transformation of teachers from digital content users into learning media creators.

Participants and Context

The study was conducted with teachers from the Gugus Dewi Kunthi elementary school cluster in Gunungpati, Semarang, Indonesia. The cluster comprises 10 elementary schools serving approximately 3,696 students. A total of 130 elementary school teachers participated in the training and media-development program.

The participating teachers had diverse levels of experience in using digital technologies for teaching. Prior to the intervention, PowerPoint was commonly used for classroom presentations, while learning videos were generally used as passive instructional resources. However, the use of Generative AI to develop interactive, contextual, and 3D cartoon-based learning media remained

limited. This context provided a relevant setting for examining how practice-oriented professional development could strengthen teachers' digital competence in the development of Generative AI-supported media. The focus on teachers' capacity development is consistent with Miao and Cukurova (2024), who position AI competency as an important component of teachers' professional development in the AI era.

Intervention Procedure

The intervention was implemented through five interconnected stages.

Stage 1: Orientation and Initial Assessment. The program began with an orientation to identify teachers' existing digital-media practices and their familiarity with Generative AI. A pre-intervention assessment was administered to establish the initial level of Generative AI literacy and its utilization for learning-media development. The assessment was aligned with the broader understanding of AI competency as involving knowledge, skills, values, and the capacity to apply AI appropriately in educational contexts (Miao & Cukurova, 2024).

Stage 2: Generative AI Training. Teachers were introduced to the basic concepts, functions, opportunities, limitations, and responsible use of Generative AI in education. The training emphasized that AI should function as a supporting technology rather than replace teachers' pedagogical judgment. This human-centered orientation is consistent with Miao and Holmes (2023), who emphasize human agency, ethical considerations, data privacy, and pedagogical validation in the use of Generative AI in education. Teachers were also introduced to several tools for generating and editing educational content, including Leonardo AI, Kling/Pika, ElevenLabs, CapCut, and Gemini.

Stage 3: 3D Cartoon Learning-Media Production. Teachers applied the skills gained during training to develop their own 3D cartoon learning media. The production process began with identifying learning objectives and curriculum content, followed by developing storylines, characters, visual scenes, narration, and animation, and concluding with final video editing. Teachers were encouraged to adapt the generated content to the characteristics of elementary school learners and the learning objectives of their respective subjects. This practice-oriented approach is consistent with Yuan et al. (2026), whose systematic review identifies instructional resource generation and curriculum design as important applications of Generative AI in teacher education.

Stage 4: Mentoring and Pedagogical Integration. Teachers received guidance as they refined their media products. Mentoring focused not only on technical quality but also on pedagogical appropriateness, contextual relevance, clarity of learning messages, and alignment with the principles of Mindful, Meaningful, and Joyful Learning. Teachers were encouraged to consider how the media could be integrated into actual learning activities rather than used merely as visual entertainment. This emphasis reflects the AI-pedagogy dimension identified by Miao and Cukurova (2024), in which teachers are expected to integrate AI into teaching in ways that support meaningful pedagogical purposes rather than technology use for its own sake.

Stage 5: Evaluation and Sustainability. Following the production and mentoring process, teachers completed the post-intervention assessment. The resulting media products were reviewed to document their characteristics and alignment with the intended pedagogical principles. The program also encouraged continued use, peer sharing, refinement, and dissemination of teacher-created media through the teacher cluster community and the Edukartun digital resource platform. Such an approach is consistent with the professional-learning dimension of the UNESCO AI

Competency Framework, which views AI competency as part of teachers' continuing professional development (Miao & Cukurova, 2024).

Instruments and Data Sources

Three main sources of data were used.

First, a Generative AI competence questionnaire was administered before and after the intervention. The instrument was used to assess teachers' level of understanding and practical use of Generative AI in educational media development. The assessment focused on teachers' ability to understand Generative AI, identify its educational applications, and apply it in the development of learning resources. These aspects correspond to the broader dimensions of AI competency for teachers, particularly AI foundations and applications, AI pedagogy, and AI for professional learning (Miao & Cukurova, 2024).

Second, observation and documentation data were collected throughout the intervention. These data included records of teachers' participation, training activities, production processes, mentoring sessions, and reflections on the use of Generative AI. The combination of quantitative and qualitative data sources supported the mixed-method design by enabling the researchers to examine changes in competence alongside evidence of teachers' actual practices (Creswell & Plano Clark, 2017).

Third, teacher-produced learning-media products were analyzed as evidence of practical competence. Product analysis considered the presence of learning objectives, storyline, characters, visual scenes, animation, narration, contextual content, and integration of Mindful, Meaningful, and Joyful Learning principles. The analysis was intended to capture not only teachers' ability to operate AI tools but also their capacity to apply AI to the development of pedagogically meaningful learning resources, consistent with the AI pedagogy dimension described by Miao and Cukurova (2024).

Data Analysis

Quantitative data were analyzed descriptively by comparing the percentage of teachers demonstrating Generative AI literacy and utilization before and after the intervention. Changes were calculated using percentage-point differences between the pretest and posttest results. The analysis focused on identifying the magnitude and direction of change rather than establishing causal effects through inferential statistical testing. Because the study used a one-group pretest–posttest design without a comparison group, the findings were interpreted as evidence of change associated with the intervention rather than definitive evidence of causal effects.

Qualitative data from observations, documentation, mentoring activities, and media products were analyzed thematically. The analysis focused on four major aspects: (1) teachers' development as learning-media creators, (2) the application of Generative AI during media production, (3) the pedagogical characteristics of the resulting 3D cartoon media, and (4) the alignment of the media with Mindful, Meaningful, and Joyful Learning.

The quantitative and qualitative findings were subsequently integrated to provide a more comprehensive interpretation of the intervention. Changes in competence were considered alongside evidence from teachers' actual media-production practices and the characteristics of their resulting products. This integration is consistent with the rationale of mixed-method research, in which quantitative and qualitative evidence are brought together to provide a more comprehensive understanding of the phenomenon under investigation (Creswell & Plano Clark, 2017).

Ethical and Responsible Use of Generative AI

The intervention emphasized responsible and human-centered use of Generative AI. Teachers were encouraged to review AI-generated content critically, verify the accuracy and appropriateness of generated materials, consider copyright and ethical issues, and adapt outputs to the characteristics of elementary school learners. These principles are consistent with UNESCO's guidance that Generative AI in education should be used through a human-centered approach that addresses ethical validation, data privacy, safety, and pedagogical appropriateness (Miao & Holmes, 2023).

Generative AI was positioned as a tool to support teachers' creative and technical processes, while decisions regarding learning objectives, content, pedagogy, contextualization, and classroom implementation remained under teachers' professional control. This positioning reflects the human-centered and teacher-agency principles emphasized in the UNESCO AI Competency Framework for Teachers (Miao & Cukurova, 2024).

The study did not collect individual student achievement data and therefore did not attempt to determine whether the intervention directly improved student learning outcomes. Instead, the study focused on changes in teachers' Generative AI competence and their capacity to produce pedagogically oriented digital learning media. This focus is consistent with the need identified by Yuan et al. (2026) for more rigorous, context-sensitive empirical research on how Generative AI is integrated into teacher education and professional development.

RESULTS AND DISCUSSION

This study involved 130 elementary school teachers ($n = 130$) from the Gugus Dewi Kunthi elementary school cluster in Gunungpati, Semarang, Indonesia. The study employed a mixed-methods intervention design, with a quantitative one-group pretest–posttest design and qualitative data collected through observation, documentation, mentoring activities, and analysis of teacher-produced learning media products. The quantitative component was used to identify changes in teachers' Generative AI competence before and after the intervention. In contrast, the qualitative component provided evidence of the media-development process, teachers' practices, and the characteristics of the resulting products.

Improvement in Teachers' Generative AI Competence

The pre- and post-intervention assessments showed substantial improvements in both Generative AI literacy and the use of Generative AI for learning media development.

Generative AI literacy increased from 10% before the intervention to 100% after the intervention, representing a gain of 90 percentage points. Similarly, the proportion of teachers utilizing Generative AI to develop learning media increased from 10% to 98%, representing an 88-percentage-point increase.

Table 1. Changes in Teachers' Generative AI Competence ($n = 130$)

Competence indicator	Pre-intervention	Post-intervention	Change
Generative AI literacy	10%	100%	+90 percentage points

Generative AI utilization for learning-media development	10%	98%	+88 percentage points
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Both post-intervention results exceeded the program target of at least 80%. The findings indicate substantial improvement in teachers' reported understanding and practical utilization of Generative AI following the intervention.

Development of 3D Cartoon Learning Media

The intervention resulted in 130 3D cartoon learning-media products developed by the 130 participating teachers. Thus, each participant produced at least one learning-media product.

The production process involved identifying learning objectives and curriculum content, developing storylines and characters, creating visual scenes, producing narration and animation, and editing the final video. Generative AI supported several stages of this process, while teachers selected, adapted, and organized the generated elements to align with their instructional objectives.

Table 2. Learning-Media Production

Indicator	Result
Participating teachers	130
3D cartoon learning media products	130
Teacher-to-product ratio	1:1

The 1:1 production ratio indicates that every participant gained direct experience in developing a digital learning resource rather than merely practicing individual AI tools in isolation.

Characteristics and Pedagogical Integration of the Learning-Media Products

Analysis of the resulting products identified several common characteristics, including 3D cartoon characters, visual scenes, animation, narration, storytelling, and subject-specific learning content. Teachers adapted these elements to the characteristics of the learners, subject matter, and learning objectives.

The products also incorporated the principles of Mindful, Meaningful, and Joyful Learning. The Mindful dimension was reflected in structured visual sequences designed to focus learners' attention on particular concepts or processes. The Meaningful dimension was represented through familiar contexts, characters, examples, and situations connected to learners' experiences. The Joyful dimension was supported by animation, narration, character-driven storytelling, and an engaging visual presentation.

These pedagogical characteristics were not treated as automatic outcomes of AI-generated content. Teachers remained responsible for decisions regarding the concepts presented, the development of the storyline, the selection of visual elements, and the contextualization of learning content. The products, therefore, demonstrated an integration of technology-supported production and teacher-led pedagogical design.

Transformation of Teachers' Roles

The qualitative evidence indicated a shift in teachers' roles during the intervention. Before the program, teachers commonly relied on conventional digital presentation tools and passive learning

videos. During the intervention, they became actively involved in designing and producing their own digital learning resources with the assistance of Generative AI.

This transformation involved more than learning to operate AI applications. Teachers engaged in curriculum interpretation, instructional planning, storytelling, visual design, content selection, and video production. Generative AI supported the creative and technical aspects of these activities, while teachers retained responsibility for learning objectives, content accuracy, contextualization, and pedagogical decisions.

The findings, therefore, indicate a shift from digital content users to learning media creators, with Generative AI serving as an enabling technology in teacher-led instructional design.

Achievement of Intervention Targets

The intervention achieved its principal targets. Both competence indicators exceeded the predefined 80% threshold, and all participating teachers produced a 3D cartoon learning media product.

Table 3. Achievement of Intervention Targets

Target indicator	Target	Achieved	Status
Generative AI literacy	≥80%	100%	Achieved
Generative AI utilization for learning-media development	≥80%	98%	Achieved
Teacher-produced 3D cartoon media	130 products	130 products	Achieved

Overall, the findings show substantial changes in teachers' Generative AI competence, accompanied by the production of contextual 3D cartoon learning media. The products further demonstrate that Generative AI was incorporated into a broader pedagogical process in which teachers retained responsibility for instructional design and contextual adaptation.

Because the study employed a one-group pretest–posttest design without a comparison group, the observed changes should be interpreted as attributable to the intervention rather than as definitive evidence of causal effects. Furthermore, because individual student achievement data were not collected, the findings do not establish direct effects on student learning outcomes.

Discussion

Strengthening Teachers' Generative AI Competence through Practice-Based Professional Development

The findings indicate that practice-based professional development can support teachers' Generative AI competence when learning is directly connected to authentic instructional tasks. Rather than introducing Generative AI as a set of standalone technological tools, the intervention engaged teachers in designing and developing actual learning resources. This approach is consistent with the AI Competency Framework for Teachers proposed by Miao and Cukurova (2024), which conceptualizes AI competence as involving not only technical knowledge but also AI pedagogy, ethical awareness, human-centered values, and professional learning.

The findings also correspond with the emerging literature on AI literacy in teacher education. Sperling et al. (2024) found that AI literacy in teacher education remains an emerging field and

identified gaps, particularly in teachers' practical and ethical knowledge. Daher (2025) similarly emphasizes that teacher AI literacy should move beyond basic technical operations toward an understanding of AI mechanisms, applications, and ethical implications. The present intervention addressed this broader understanding by combining AI concepts with an authentic media-production task.

The observed improvement is therefore relevant not simply as an indicator of increased familiarity with AI tools, but also as evidence of teachers' engagement in applying AI to produce learning resources. This finding supports research emphasizing that teachers' digital competence develops more meaningfully when technology is integrated into purposeful instructional practice rather than limited to technical training (Claro et al., 2024; Ng et al., 2023). However, because the study did not include a control or comparison group, the observed changes cannot be attributed exclusively to the intervention. They are more appropriately interpreted as changes in competence occurring during the intervention period.

From Digital Content Users to Learning-Media Creators

A key contribution of the intervention was the shift in teachers' practical roles from primarily using existing digital content to designing and producing their own learning resources. Developing 3D cartoon media required teachers to determine learning objectives, select content, construct stories and characters, organize visual scenes, prepare narration, and refine the final product.

This finding is consistent with Wohlfart and Wagner (2023), who emphasize that educational digitalization involves changes in teachers' professional practices rather than simply the adoption of new technologies. It also reflects Miao and Cukurova's (2024) view that meaningful use of AI should be embedded in teachers' pedagogical and professional practices. In this process, Generative AI served as an enabling technology within a broader instructional design process.

The transformation also has implications for teachers' professional identity. Lan (2024), examining AI-enhanced teacher training, identified tensions concerning the relationship between human expertise and technological systems and highlighted different ways teachers may position AI in relation to their professional roles. In the present study, teachers retained responsibility for curriculum interpretation, instructional planning, content selection, contextualization, and pedagogical decisions. This suggests that the use of AI did not need to displace teacher agency; rather, it could be incorporated into a teacher-led design process. The distinction between AI-generated content and teacher-designed learning media is therefore important because the educational value of Generative AI depends on teachers' ability to select, modify, evaluate, and contextualize its outputs.

Generative AI-Based 3D Cartoon Media and Deep Learning.

The developed media demonstrate how Generative AI can be connected with the principles of Mindful, Meaningful, and Joyful Learning. These principles provide a pedagogical framework for determining how technology-supported media should be designed, rather than merely serving as labels for visually attractive digital content.

Mindful Learning can be supported through deliberately structured visual sequences that focus learners' attention on important concepts or processes. Meaningful Learning can be strengthened when stories, characters, and situations are connected to learners' familiar experiences. Joyful Learning can be supported through animation, storytelling, narration, and character-based presentation. These interpretations are consistent with the Pembelajaran Mendalam framework

promoted by Indonesia's Ministry of Primary and Secondary Education (Kementerian Pendidikan Dasar dan Menengah, 2025, 2026).

Importantly, the findings also highlight that animation or Generative AI does not automatically produce deep learning. Its pedagogical value depends on learning objectives, contextualization, learning activities, and teachers' instructional decisions. This point is consistent with the literature on AI literacy, which emphasizes the importance of pedagogical and ethical knowledge alongside technical competence (Sperling et al., 2024; Daher, 2025). Thus, the contribution of 3D cartoon media lies not merely in visual appeal but in its purposeful integration into learning.

Generative AI as a Teacher-Led Design Support

The findings support a human-centered approach to Generative AI in teacher professional development. During the intervention, AI supported creative and technical production, while teachers remained responsible for pedagogical decisions. This orientation is consistent with Miao and Holmes (2023), who emphasize human agency, ethical considerations, privacy, safety, and pedagogical validation in the use of Generative AI in education, as well as Miao and Cukurova (2024), who emphasize a human-centered mindset and AI pedagogy.

Recent research further reinforces the need for this approach. Daher (2025) argues that teacher AI literacy should encompass AI mechanisms, applications, and ethical implications rather than being reduced to tool operation. Similarly, Yuan et al. (2026) identify instructional resource generation and curriculum design as important applications of GenAI in teacher education while highlighting the need for stronger empirical and context-sensitive evidence. The present study provides practical evidence from an elementary school teacher professional development context in which GenAI was embedded in a complete learning media development process.

AI can generate images, characters, narration, or animation. However, it cannot independently determine whether these outputs are appropriate for particular learning objectives, learners' developmental levels, cultural contexts, or classroom conditions. Teachers, therefore, remain responsible for evaluating and adapting AI-generated materials. Professional development should consequently extend beyond prompt writing and tool operation to include output evaluation, identification of inaccuracies, contextual adaptation, ethical considerations, copyright awareness, and instructional integration.

Practice-Based Professional Development and Sustainable Capacity Building

The intervention suggests that Generative AI professional development becomes more meaningful when organized around authentic production tasks. Yuan et al. (2026) identify instructional-resource generation and curriculum-related work as important applications of Generative AI in teacher education, while also highlighting the need for pedagogical and contextual adaptation. Panday-Shukla (2025) similarly identifies the need for additional professional development opportunities, as pre-service teachers and teacher educators may be interested in GenAI yet have limited AI literacy.

In this study, teachers did not learn Generative AI solely through demonstrations; they applied it to produce complete learning resources. This process connected technological learning with curriculum interpretation, instructional design, visual communication, and classroom relevance. It also created opportunities for professional collaboration through product sharing, peer feedback, and refinement.

Sustained adoption, therefore, requires more than a single training session. A continuing cycle of training, production, mentoring, classroom implementation, sharing, refinement, and replication can provide teachers with repeated opportunities to apply and improve their practice. This is particularly important because AI competence is not a static technical capability but an evolving form of professional knowledge that must respond to changes in AI technologies and educational practices (Miao & Cukurova, 2024; Sperling et al., 2024). Teacher professional communities and shared digital repositories, such as Edukartun, can further support this process by enabling teachers to exchange and develop learning resources collaboratively.

Theoretical and Practical Implications

Theoretically, this study connects three dimensions that are often examined separately: teacher AI competence, development of Generative AI-supported learning media, and deep learning-oriented pedagogy. The findings suggest that these dimensions can be integrated through authentic production activities in which teachers apply AI to address concrete pedagogical needs. This integration is consistent with emerging conceptualizations of AI literacy that emphasize technical, practical, ethical, and pedagogical dimensions (Sperling et al., 2024; Daher, 2025).

In practice, teacher professional development should combine AI literacy with authentic instructional design tasks. Teachers should be positioned as creators and pedagogical decision-makers rather than passive users of AI-generated content. Training should also systematically address content verification, ethical and copyright considerations, contextual adaptation, and pedagogical integration. Professional learning communities can strengthen these processes by providing opportunities to share, review, and improve teacher-created media.

The findings also suggest that professional development should acknowledge teachers' professional identity when introducing AI. AI-enhanced training may influence how teachers perceive the relationship between their existing expertise and new technological capabilities (Lan, 2024). Therefore, professional development should frame AI as a complement to teachers' professional knowledge rather than as a replacement for pedagogical expertise.

Limitations and Future Research

Several limitations should be considered. First, the one-group pretest–posttest design did not include a comparison group; therefore, the observed changes cannot be interpreted as definitive evidence of causal effects of the intervention. Future studies could employ quasi-experimental or experimental designs to provide stronger evidence.

Second, the study focused on teachers' Generative AI competence and the characteristics of the media they produced rather than direct student learning outcomes. Future research could investigate whether and under what conditions teacher-created Generative AI media are associated with student engagement, motivation, conceptual understanding, or learning outcomes.

Third, the study was conducted within one elementary school cluster in Semarang, which limits direct generalization to other contexts. Studies involving different regions, school characteristics, teacher profiles, and levels of technological readiness could provide broader evidence. Finally, given the rapid development of Generative AI, future research should emphasize transferable competencies such as critical evaluation, pedagogical design, ethical judgment, contextualization, and teacher agency rather than dependence on specific AI platforms. This direction is also consistent with recent systematic reviews calling for more rigorous, longitudinal, and context-sensitive research on GenAI in teacher education (Yuan et al., 2026).

Overall Interpretation

Overall, the findings suggest that the educational value of Generative AI lies less in automated content generation than in how teachers direct, evaluate, contextualize, and pedagogically integrate AI-supported resources. The intervention connected AI literacy to the production of concrete learning media and positioned teachers as active designers of digital learning resources.

In elementary education, Generative AI-based 3D cartoon media can help translate curriculum content into visual and contextual learning experiences aligned with Mindful, Meaningful, and Joyful Learning. However, such potential depends on teachers' competence, professional judgment, and the learning activities in which the media are embedded. Generative AI is therefore best understood as an enabling technology within teacher-led pedagogical practice rather than as a substitute for teachers' professional expertise.

CONCLUSION

This study demonstrates that practice-based professional development using Generative AI can support elementary school teachers in strengthening their competence to develop digital learning media. The development of 3D cartoon media encouraged teachers to move from digital content users to learning-media creators and pedagogical decision-makers. Generative AI supported the creation of visual, contextual, and engaging media aligned with the principles of Mindful, Meaningful, and Joyful Learning. However, its pedagogical value depends on teachers' ability to evaluate, adapt, and integrate AI-generated outputs in line with learning objectives. Given the one-group pretest–posttest design without a comparison group and the use of direct measures of student learning outcomes, the findings do not establish causal effects on student achievement. Overall, Generative AI can serve as an enabling technology to strengthen teachers' capacity to create digital learning resources, while maintaining teacher agency and pedagogical decision-making at the center of the learning process.

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