

# Harnessing artificial intelligence for preservice teachers' development: A scoping review of applications, benefits, and challenges

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## ABSTRACT

The integration of artificial intelligence (AI) into teacher education is profoundly reshaping the professional development of preservice teachers. This scoping review examines the application of AI in this context, aiming to delineate its characteristics, benefits, and challenges. Following the PRISMA-ScR guidelines, this study conducted a systematic search of three academic databases (Web of Science, ScienceDirect, and EBSCOhost) for empirical research published between 2020 and 2025. After screening an initial pool of literature, 55 studies were included for analysis. The findings reveal a diverse landscape of AI applications, technologies, and subject distributions in preservice teacher development. The analysis indicates that AI can significantly enhance various competencies, including instructional design, subject-specific instruction, practical teaching skills, evaluation efficiency, reflective practice, critical thinking, technology integration, and pedagogical innovation. However, several challenges were identified, encompassing technical limitations, the risk of over-reliance, ethical and social concerns, and barriers to implementation. This review advocates for a proactive approach to leveraging AI's innovative potential while reducing its associated risks. Future research should focus on the continual evaluation and adaptation of AI tools to ensure they effectively support and advance the professional development of preservice teachers.

## 1. Introduction

The growth of artificial intelligence (AI) in education has prompted global recognition of its potential to transform teacher training, leading to the formulation of supportive national and international policies. The UNESCO mandates the effective integration of AI into educational systems, positioning it as a critical tool for professional development [1]. Similarly, the European Union has called for improving enhancing teachers' digital literacy and supports the use of AI to improve instructional efficiency and quality [2]. In the United States, the Office of Educational Technology emphasizes the need to provide teachers with sufficient and continuous professional training to improve their digital literacy and technology application capabilities, and to help teachers adapt to emerging technologies and effectively integrate them into their teaching practices [3]. Collectively, these international policies underscore a commitment to deeply integrating AI into teacher professional

development to enhance the quality of teacher training.

As the foundational stage of a teacher's career, preservice teacher education is undergoing a paradigm shift from traditional models to technology-enhanced pedagogy [4,5]. Preservice teachers are at the forefront of education in the future. Effectively preparing these future educators requires critically examining how AI can be leveraged to refine teacher education programs and improve learning outcomes. While the introduction of AI presents significant opportunities for preservice teacher education, its effective integration also involves challenges and risks that require careful consideration [6].

Empirical research on AI applications in teacher education, including elementary and secondary levels, has predominantly focused on in-service teachers [7–9], with only a few studies focusing on preservice teachers [6]. For instance, Tan et al. [8] found that 65 % of studies focused on the application of AI in teaching, while only 35 % explored AI's role in enhancing teacher professional development. Among

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existing studies utilizing the Technology Acceptance Model (TAM), Wang et al. examined factors influencing higher education teachers' intentions to use AI tools, considering anxiety, self-efficacy, attitudes toward AI, perceived ease of use, and perceived usefulness [9]. Similarly, Choi et al. applied TAM to investigate in-service teachers' trust in AI educational tools [7], finding that perceived ease of use was the most significant factor affecting their acceptance. Using the same framework, Zhang et al. identified perceived usefulness and perceived ease of use as key factors shaping preservice teachers' intentions to adopt AI technology [6]. Despite the growing scholarly interest in AI's role in teacher education, a comprehensive synthesis of the current landscape—including the applications, benefits, and challenges of AI for preservice teachers' professional development—remains absent from the literature [10,11].

This scoping review aims to address the gap in the literature by systematically mapping existing research on AI in teacher education. Its purpose is to shed light on the developmental prospects and core challenges associated with AI, providing valuable insights for educators, policymakers, and researchers dedicated to harnessing AI's potential to enhance preservice teacher education. Accordingly, this review is guided by the following research questions:

RQ1: What are the characteristics of AI applications in preservice teachers' professional development, including application scenarios, technologies, and disciplinary contexts within empirical studies?

RQ2: What are the documented benefits and opportunities of using AI to support the professional growth of preservice teachers?

RQ3: What are the primary challenges, limitations, and risks associated with the application of AI in this context?

## 2. Research methods

### 2.1. Study design

This study employed a scoping review methodology to systematically map the existing empirical research on the application of AI in preservice teacher education. This approach was selected due to the exploratory nature of the research questions and the objective of identifying the key characteristics, scope, and knowledge gaps within this emerging field. The review was structured according to the five-stage framework proposed by Arksey and O'Malley [12]: (1) identifying the research questions; (2) identifying relevant studies; (3) study selection; (4) charting the data; and (5) collating, summarizing, and reporting the results. Furthermore, the reporting of this review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [13]. The PRISMA-ScR guideline was used to ensure comprehensive and transparent reporting of our methodology and findings. It provided a structured framework for presenting key elements of the review, including the title, abstract, introduction, methods, results, and discussion. Specifically, we followed the PRISMA-ScR checklist to document the research question, eligibility criteria, search strategy, data charting procedures, and the presentation of results. In addition, the study selection process is summarized with a PRISMA-ScR flow diagram that depicts the movement of records through the review phases (identification, screening, eligibility, and inclusion).

### 2.2. Search strategy

A systematic search was conducted in three major electronic databases: Web of Science, ScienceDirect, and EBSCOhost. The search was limited to peer-reviewed articles published in English between January 1, 2020, and May 1, 2025, to ensure the inclusion of the most recent advancements in the field. The search string was constructed using Boolean operators (AND/OR) to combine two key concepts: AI technologies and preservice teachers. A scoping review requires high-sensitivity search terms with proven scholarly relevance. Although

various AI applications exist, ChatGPT, released in November 2022, marked the first widely accessible generative AI tool to gain significant global scholarly attention in education. Early research predominantly focused on ChatGPT (and GPT models) as case studies, highlighting its disruptive emergence and transformative potential. Hence, the specific keywords used in this study were:

- Concept A (AI): ("artificial intelligence" OR "AI" OR "generative artificial intelligence" OR "ChatGPT" OR "GPT" OR "natural language processing")
- Concept B (Preservice Teachers): ("preservice teacher" OR "student teacher" OR "pre-service teacher" OR "initial teacher education")
- Combination: Concept A AND Concept B

In addition to the database search, we conducted a manual search using the snowballing technique [14]. This included scanning the reference lists of included studies (backward snowballing) and identifying articles that cited them via Google Scholar (forward snowballing). All identified records were screened against the study's eligibility criteria by two independent reviewers to ensure consistency in the study selection process.

### 2.3. Study selection and screening

The study selection process was conducted in multiple stages (see Fig. 1). The initial search yielded 1,688 records. After importing all records into EndNote X20, duplicates ( $n = 74$ ) were identified and removed. Subsequently, two researchers independently conducted a double-blind screening of the remaining articles. Specifically, both reviewers screened the same set of articles at each of the following two phases: (1) title and abstract screening, and (2) full-text screening:

*Phase 1: Title and abstract screening:* The titles and abstracts were screened by both reviewers independently based on predefined inclusion and exclusion criteria. Studies were excluded if they did not involve preservice teachers, were not set in an educational context (e.g., medical AI research), or did not feature an AI-based intervention. This phase resulted in the exclusion of 1,423 articles.

*Phase 2: Full-text review:* The remaining articles underwent a full-text review by both reviewers independently to confirm their eligibility. At this stage, non-empirical studies (e.g., reviews, theoretical papers, commentaries) and articles for which the full text was inaccessible were excluded.

Disagreements between the reviewers at each stage were resolved among research team through discussion until a consensus was reached. This rigorous process yielded a final sample of 55 studies for inclusion in the review.

### 2.4. Data extraction and analysis

A standardized data extraction form was developed to chart key information from the 55 included articles. The extracted data points included: author(s), publication year, country of origin, research methodology, participant characteristics (i.e., research object), academic discipline, AI technology type, and the specific application scenario. A comprehensive summary of this information is presented in the Appendix. To synthesize the findings and address the research questions, the extracted data were analyzed using Reflexive Thematic Analysis (RTA), as outlined by Braun and Clarke [15]. This involved an iterative process where researchers repeatedly familiarized themselves with the literature. To ensure reliability and consistency in the coding process, we conducted an interrater reliability assessment. Two researchers independently coded a random sample of 10 articles (18 %) using MAXQDA 2024. The initial inter-coder agreement, measured by Cohen's kappa, was 0.75. The coders then met to discuss and resolve discrepancies, which led to a refinement of the coding framework. A second round of independent coding on another 5 articles (9 %) yielded a

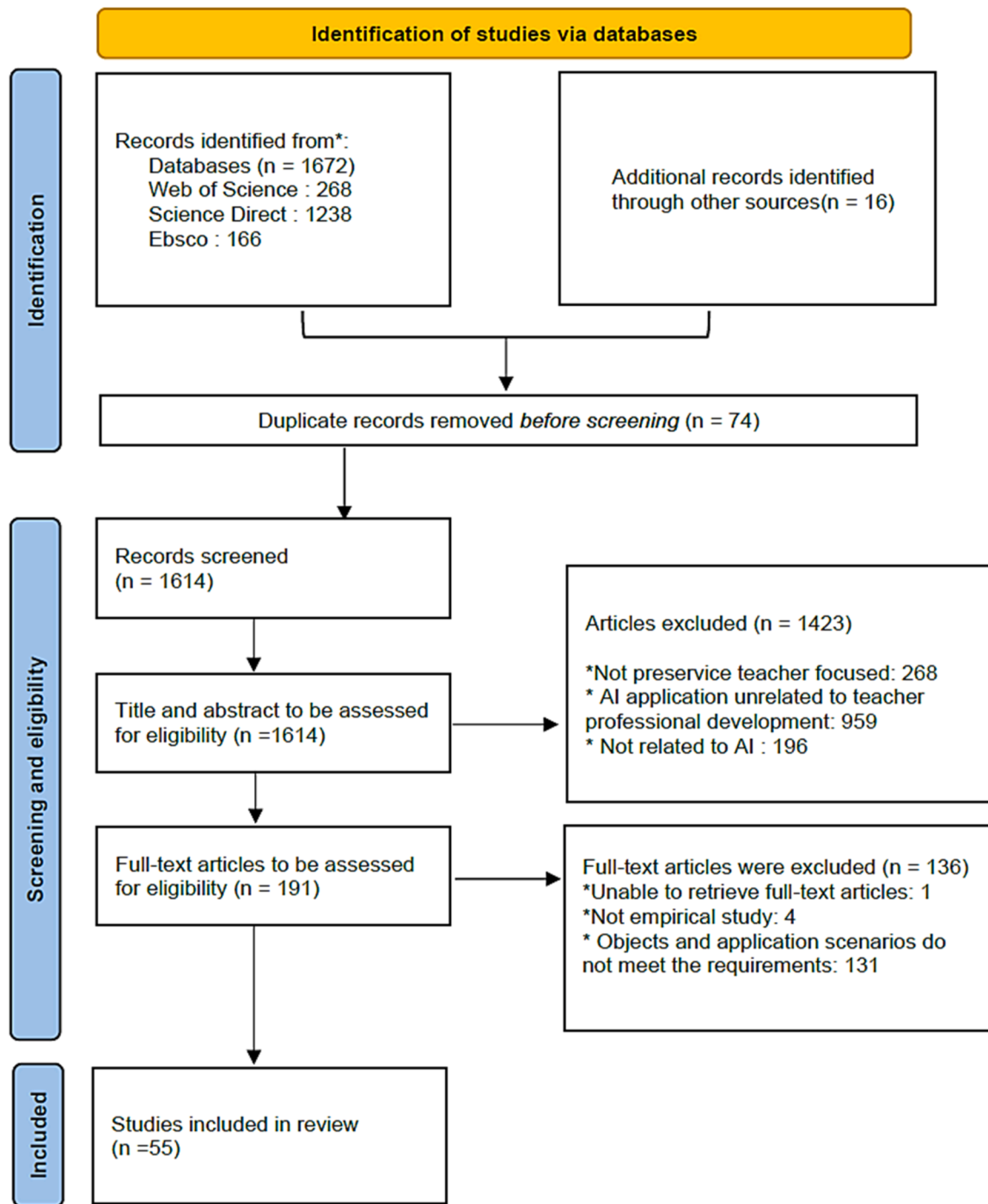


Fig. 1. A flow diagram summary of the selection of reviewed studies.

Cohen's kappa of 0.88, indicating excellent agreement. After establishing reliability, the remaining articles were divided between the two coders for efficient analysis, with ongoing meetings to address any uncertainties. Through this process, the researchers systematically coded the data in MAXQDA 2024 and generated, reviewed, and refined themes related to the characteristics, benefits, and challenges of AI in preservice teacher education.

### 3. Result

The final sample for this scoping review comprised 55 empirical studies (see Appendix [16–70]). The following sections present the

descriptive characteristics of these studies, and the thematic findings related to the research questions.

#### 3.1. Overview of included studies

The included studies demonstrated a broad geographic distribution, spanning 18 different countries. Research output was most prolific in China (n = 12), followed by South Korea (n = 10), the United States (n = 5), Germany (n = 5), and Turkey (n = 4). Several countries contributed two or three studies each (e.g., Israel, Spain, Australia), with eight countries contributing one study each. One study involved a collaboration between the United States and Spain.

A significant publication trend was observed, indicating a rapid acceleration of research in this area. Most articles were published very recently, with 44 % (n = 24) from 2024 and 38 % (n = 21) from 2025. One article, slated for 2026 publication, was included as it was made available online in 2025 within our search period. Regarding methodology, mixed methods research was the predominant approach, used in 58 % (n = 32) of the studies. This was followed by qualitative methods (31 %, n = 17) and quantitative methods (11 %, n = 6). Collectively, the studies involved a total of 3,098 preservice teacher participants.

3.2. Research question 1: characteristics of AI applications

The first research question examined the characteristics of AI applications in preservice teachers’ professional development, focusing on application scenarios, AI technologies, and disciplinary contexts.

3.2.1. Application scenarios

The analysis revealed that AI is being applied across six primary scenarios to foster key professional competencies in preservice teachers (see Table 1 for a detailed mapping). First, generative AI (GenAI) is widely used in instructional design and lesson preparation, assisting with lesson plan generation, optimization of teaching goals, and curriculum development [17,21,56,68]. Second, in subject-specific teaching practice, AI demonstrates strong adaptability and supports instruction in mathematics [25,62], science [67], language [32], and history [38]. Third, for teaching practice and simulation training, AI-powered virtual students [27,48] and virtual classroom environments [43,46] provide preservice teachers with immersive platforms for practice, while feedback from AI virtual tutors enhances the effectiveness of teaching strategies [31,36]. Fourth, in teaching evaluation and feedback, AI assists with consistent homework scoring [24] and automatic test question generation [60]. Fifth, for reflection and critical thinking, preservice teachers use tools such as AI dashboards [44] and reflective coaches [69] to develop reflective teaching skills and cultivate critical thinking by evaluating AI-generated content [20]. Sixth, in terms of technology integration and teaching innovation, AI has significantly advanced preservice teachers’ knowledge of technology integration (TPACK) [18,61], directly enabling innovative teaching practices.

3.2.2. AI technologies employed

The analysis identified a distinct hierarchy in the types of AI technologies used (see Table 2). GenAI was the predominant technology, featured in 52 % of the included studies. Within this category, ChatGPT was the most frequently specified tool, utilized in 66.7 % of the GenAI studies, which corresponds to 34.7 % of the total sample. There are other prominent AI technologies. For example, dialogue and interaction systems such as natural language processing (NLP) and chatbots were central to 20.0 % of the applications, primarily for facilitating interactive learning and analysis. Specialized educational systems which includes virtual reality (VR) simulations and intelligent tutoring systems (ITS), was present in 14.7 % of studies, typically designed for specific pedagogical scenarios. Machine learning, such as custom-trained models

Table 1  
Application scenarios.

| No | Application scenario                           | Included studies number                  |
|----|------------------------------------------------|------------------------------------------|
| 1  | instructional design and lesson preparation    | [17,19,21,49,52,54,56,57,65,68]          |
| 2  | Subject teaching practice                      | [18,25,32–34,38,40,41,47,50,53,58,62,67] |
| 3  | Teaching practice and simulation training      | [16,22,27–31,36,39,42,43,46,48,63,64,70] |
| 4  | Teaching evaluation and feedback               | [24,34,59,60,66]                         |
| 5  | Reflection and critical thinking training      | [20,23,26,35,37,44,45,69]                |
| 6  | Technology integration and teaching innovation | [18,21,33,50,51,55,61,64]                |

Table 2  
AI technologies employed.

| AI technology type                       | Specific AI technology/tools                                                                                                      | Frequency | Percentage |
|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|-----------|------------|
| GenAI applications                       | ChatGPT, GPT-3.5, GPT-4, text-DaVinci-003, Microsoft Copilot, Bing Chat, DALL-E3, Image-GAI, Invideo, Twee, ERNIE Bot, Monica Bot | 39        | 52.0 %     |
| Education-specific systems               | SimInClass, VR-AI Assisted simulation, SPOT Virtual, virtual student, YiClass, Quanjin, intelligent tutoring system, Quizizz AI   | 11        | 14.7 %     |
| AI conversational interaction technology | Google Dialogflow, IBM Watson, Kuki, Chatfuel, Natural Language Processing (NLP), Text Analysis, Rule-based NLP                   | 15        | 20.0 %     |
| Machine learning technology              | BERT, deep neural networks, XAI (Explainable AI)                                                                                  | 7         | 9.3 %      |
| Evaluation and feedback systems          | Automated Assessment SAAI, Studiosity, Automated Feedback Tool, Artificial Neural Network Feedback System                         | 3         | 4.0 %      |

and other machine learning applications, were used in 9.3 % of the research. Automated assessment systems were the least common, appearing in only 4.0 % of the reviewed literature. A notable finding was that over half of the studies employed a combination of multiple AI technologies (e.g., GenAI integrated with NLP), suggesting a trend towards multimodal AI solutions. The prevalence of easily deployable tools like ChatGPT also indicates a practical focus on accessible and efficient solutions within the field.

3.2.3. Disciplinary distribution of AI applications

Regarding disciplinary focus, the application of AI was highly concentrated in specific subject areas. Of the 55 included articles, 40 specified a clear disciplinary context (see Table 3). Among these 40 subject-specific studies, language education was the most represented field, accounting for 42.5 % (n = 17). This broad category included research in English, Turkish, EFL (English as a Foreign Language), and Chinese contexts. Mathematics was the second most frequent discipline, featured in 27.5 % (n = 11) of the studies. Other disciplines were represented as follows: (a) Interdisciplinary/comprehensive subjects: 10 % (n = 4). In these studies, science and mathematics were the most common subjects to be integrated; (b) Science and Physics: each accounted for 7.5 % (n = 3); (c) History and Chemistry: each accounted for 2.5 % (n = 1). This distribution highlights a primary focus on applying AI in language and mathematics education, with emerging interest in science and interdisciplinary studies.

3.3. Research question 2: benefits and opportunities of AI applications

The analysis of the included studies identified five primary domains where AI offers significant opportunities to promote the professional development of preservice teachers (see Table 4).

Table 3  
Disciplinary distribution.

| Subject                             | Frequency | Percentage |
|-------------------------------------|-----------|------------|
| Languages (English, other language) | 17(13, 4) | 42.5 %     |
| Mathematics                         | 11        | 27.5 %     |
| Physics                             | 3         | 7.5 %      |
| Chemistry                           | 1         | 2.5 %      |
| Science                             | 3         | 7.5 %      |
| History                             | 1         | 2.5 %      |
| STEM/Comprehensive Subjects         | 4         | 10.0 %     |
| Total                               | 40        | 100.00 %   |

**Table 4**  
Benefits and opportunities of AI applications.

| No | Benefits and opportunities of AI applications                     | Frequency | Included studies number                                 |
|----|-------------------------------------------------------------------|-----------|---------------------------------------------------------|
| 1  | Enhancing the quality and efficiency of instructional design      | 21        | [16,17,19,21,29,34,35,37,47,49,51–54,56,57,61,64–66,68] |
| 2  | Enhancing subject-specific pedagogy and practical teaching skills | 26        | [19,22,23,25,27–31,33,35–43,48,53,62–64,67,69]          |
| 3  | Improving the quality and efficiency of teaching evaluation       | 6         | [24,34,58–61]                                           |
| 4  | Fostering teaching reflection and critical thinking               | 15        | [20–23,26,33,35,44–46,51,56,59,69,70]                   |
| 5  | Advancing technology integration and pedagogical innovation       | 5         | [18,21,33,50,61]                                        |

3.3.1. *Enhancing the quality and efficiency of instructional design*

AI was frequently reported to be a valuable partner in the instructional design process, providing support across the entire workflow [16, 17,19,21,29,34,37,47,51–53,56,57,61,64,65,68]. Studies indicate that AI tools enhance innovation, enable personalization, improve the quality of instructional materials, enrich the supply of resources, and optimize the design process itself, ultimately saving time.

AI tools were found to help preservice teachers overcome conventional thinking by providing multiple perspectives and novel ideas for teaching activities, strategies, and methods [16,17,19,21,37,53,54,56,57,65]. For example, AI enhances the depth, structural coherence, and quality of lesson design by providing structured frameworks and drafts [29], clarifying course structures and stage requirements [17], generating detailed course plans [53], and assisting in the creation of interactive and engaging teaching plans [52,56,61]. Furthermore, AI supports the creation of personalized and differentiated lesson plans tailored to diverse student abilities, needs, and interests [16,34,51,56,57,68]. As a resource engine, AI broadens access to diverse materials (e. g., text, images, videos) [56] and assists in generating drafts of teaching content [16,37,47,64]. Beyond quantity, AI also facilitates the intelligent adaptation of these resources to ensure they align with specific topics [37,61] and student needs [53,56].

A primary benefit of AI is the significant reduction in time and effort required for instructional design [16,29,34,53,54,56,57,64,65]. By automating repetitive tasks like resource searching and initial drafting, AI frees preservice teachers to focus on deeper pedagogical considerations. For example, AI automates and accelerates resource searching, screening, and information collection [16,17,53], and can generate teaching plan drafts [29,56,57,64], freeing preservice teachers from repetitive tasks and allowing them to focus on deeper instructional planning [16]. By optimizing the overall workflow [16,17,29,37,61], AI streamlines the preparation and implementation of lesson designs, enhances information integration [37], and simplifies task execution [16, 61]. This significantly improves the efficiency and coherence of the design process, enabling preservice teachers to concentrate on core teaching decisions and plans.

3.3.2. *Enhancing discipline-specific teaching abilities and practical teaching effectiveness*

The review found that AI provides targeted support for preservice teachers by strengthening discipline-specific teaching abilities and enhancing their practical teaching effectiveness through innovative tools and platforms. In the domain subject-specific pedagogy, AI acts as both a consultant and a tool. For example, in mathematics education, AI-powered systems have been used to deconstruct geometric proofs, enhance geometric thinking through AI-assisted AR, and evaluate students’ proof skills with adaptive systems [25,33,62]. Similarly, in science education, AI serves as a subject teaching consultant, assisting preservice teachers in designing inquiry-based learning sequences and

developing active teaching strategies [19,67]. Tools like Copilot supports preservice science teachers in engaging all students by facilitating methods such as inquiry-based learning and collaborative activities [53]. In language teaching, AI chatbots provide immersive, contextualized practice and personalized feedback on linguistic skills [40,41]. This trend extends to the humanities and interdisciplinary studies, where AI helped preservice teachers reflect on teaching historical writing [38] and acts as a general tutor for integrating STEM knowledge [37].

To translate pedagogical knowledge into practical competence, AI significantly improves teaching practice through three main applications: AI-powered virtual students [27–30,39,42,48,64], AI-driven feedback and tutoring systems [22,23,28,31,36,69], and immersive virtual classroom environments [43,63]. A foundational application is the use of AI-powered virtual students, which provide a safe, low-risk environment where preservice teachers can practice and refine their teaching skills [28,30,39,64]. Interacting with these simulations has been shown to improve questioning skills, responsiveness to student thinking, and the use of effective guidance strategies [27,64].

AI-driven feedback and tutoring systems further enhance this development by creating a practice-feedback-iteration growth loop. For instance, adaptive feedback systems such as AI Coach help preservice teachers monitor their instructional behaviors, critically analyze teaching experiences [69], and identify key teaching challenges [23]. These AI-driven systems also improve metacognitive self-monitoring and provide comprehensive analysis of classroom interactions [27,29, 30]. Moreover, immersive virtual classroom environments integrate these tools to allow for repeated practice of essential skills like classroom management [43]. GenAI-enhanced simulations have also been shown to improve problem-solving abilities [63]. This training not only refines practical teaching skills but also boosts preservice teachers’ sense of self-efficacy and confidence in their teaching abilities [27,29].

3.3.3. *Improving the quality and efficiency of teaching evaluation*

AI integration was found to enhance preservice teachers’ assessment capabilities, particularly in scoring and item generation. This was particularly evident in the areas of scoring and assessment item generation [24,58–60]. Regarding scoring, AI automates routine grading tasks [24,34,61], freeing preservice teachers for more reflective work [24,58]. As an objective reference, systems like ChatGPT-4 and SAAI were reported to improve the consistency and fairness of scoring by reducing subjective bias [24,59]. In addition to evaluation, AI tools have transformed assessment creation. Systems such as KR-Item-Generator and Q-Craft efficiently generate large volumes of high-quality, cognitively challenging assessment questions that align with curriculum standards, providing professional inspiration and examples [60].

3.3.4. *Fostering teaching reflection and critical thinking*

The literature indicates that AI tools can foster deeper teaching reflection and enhance critical thinking skills. AI tools act as reflective scaffolds. AI dashboards were shown to shift reflective discussions from superficial description to deeper analysis [23]. For example, the BERT model can automatically classify written reflections, significantly improving the efficiency and accuracy of analyzing preservice teachers’ reflective writing [45]. AI coaches supported metacognitive development through structured feedback [69], and AI-driven data analysis helped create an iterative “practice-reflection-improvement” cycle [22, 56,59]. AI often functions as a cognitive trigger. Preservice teachers were required to critically evaluate AI-generated outputs, such as mathematical answers [20], programming code [33], or grammar suggestions [46]. This process of questioning, verifying, and correcting AI content directly trains information discrimination, logical reasoning, and creative problem-solving skills [21].

3.3.5. *Advancing technology integration and pedagogical innovation*

Finally, AI applications were found to support the development of

preservice teachers’ technology integration capabilities, often framed by the Technological Pedagogical Content Knowledge (TPACK) model. Studies reported improvements across TPACK dimensions. AI tools enhanced basic Technical Knowledge (TK) [33,50,61], while AI-assisted tasks deepened Content Knowledge (CK) and Pedagogical Knowledge (PK) [18,21,33]. The most significant growth was noted in integrative knowledge (TPK, TCK, TPACK) [18,21,50], as AI helped preservice teachers embed technology into their specific teaching strategies and content. For example, ChatGPT can be used to optimize problem formulation, while AR can help visualize geometric relationships. This process also increased their confidence and reduced technology-related anxiety because AI lowers the technical barrier and provides a safe environment for experimentation [33]. By strengthening their TPACK framework, preservice teachers were better able to innovate. For example, they used ChatGPT to connect abstract mathematical problems to real-world contexts or to design personalized [18], interactive chatbot-based activities for language learning [50].

3.4. Research question 3: Challenges, risks, and limitations of AI applications

The final research question addressed the limitations, risks, and challenges associated with using AI in preservice teachers’ professional development. The analysis revealed four major categories of challenges: technical limitations, the risk of over-reliance, ethical and social risks, and practical implementation barriers (see Table 5).

3.4.1. Technical limitations

The first major category of challenges identified in the literature relates to the technical limitations of current AI systems, particularly concerning content accuracy, linguistic processing, and reliability. A fundamental issue is the unreliability of AI-generated content, with numerous studies reporting the presence of factual errors [17–21,29,33], outdated information [18,19,21,57], and fictitious citations [16,55]. The output was often described as superficial or template-based [17,34,35,55], lacking the depth required for complex tasks [44,62,64] and sometimes exhibiting logical breaks [48,55]. Furthermore, limitations in language processing were noted, especially in non-English contexts where AI struggled with cultural adaptation [17], translation [18], and ambiguity [24], resulting in unnatural expressions [36]. The effectiveness of AI-generated pedagogical feedback was also frequently questioned, as it often lacked theoretical grounding [69], situational adaptability [22,70], and cultural sensitivity [28], sometimes even conflicting with the assessments of human tutors [23]. Finally, the authenticity of interactions within simulated environments was a concern, with virtual students exhibiting mechanical responses [27,42], an inability to process non-verbal cues [46], and non-human cognitive biases such as overlooking confirmed problem-solving steps [48], hindering the development of a genuine teacher-student emotional connection [30,40].

Table 5  
Challenges, risks, and limitations of AI applications.

| No | Challenges, risks, and limitations of AI applications | Frequency | Included studies number                                    |
|----|-------------------------------------------------------|-----------|------------------------------------------------------------|
| 1  | Technical limitations                                 | 28        | [16–24,27–30,33–36,40,42,44,46,48,55,57,62,64,69,70]       |
| 2  | Risks of over-reliance                                | 19        | [16,19–21,27,30–33,37,41,51,55,57,58,60,61,64,68]          |
| 3  | Ethical and social risks                              | 20        | [16,19,21,26,34,37,38,41,47,51,53,54,56,60,61,64–66,68,70] |
| 4  | Implementation barriers                               | 16        | [20,21,27,28,33,37,40,47,51,52,54,60,64–67]                |

3.4.2. Risks of over-reliance

A second significant challenge is the risk of over-reliance on AI, which was reported to potentially degrade professional skills and undermine student cognition. This risk first manifests as a decline in preservice teachers’ professional abilities. The direct adoption of AI-generated lesson plans was found to weaken creative instructional design [16,57], while reliance on chatbots could diminish situational coping skills in real interactions [27,41]. More deeply, when preservice teachers use AI suggestions without critical reflection [21], it can lead to a gradual degeneration of their own reflective depth [31], evaluation skills [60], and independent problem-solving abilities [33,68]. This over-reliance can extend to students, potentially weakening their cognitive autonomy by reducing their motivation for independent exploration [19,32] and leading to an atrophy of critical thinking [37]. The misuse of AI was also linked to a decline in students’ expressive writing skills [55] and creative imagination [64], effectively transferring cognitive labor to the technology [20,58]. This trend contributes to a potential erosion of humanistic values in teaching, as the efficiency of AI’s mechanized processes can overshadow the need for emotional interaction [61], leading to alienation between teachers and students [27] and promoting rigid, standardized teaching decisions [51].

3.4.3. Ethical and social risks

Beyond technical and pedagogical issues, the literature highlighted numerous ethical and social risks. A primary concern is the threat to data privacy and security, as the collection and processing of student information in AI systems create a significant risk of data leakage [16,19,21,26,66]. AI chatbot systems must process large amounts of data, including personal information and learning records, making secure storage and usage a critical concern [41,47,68]. Without robust data protection mechanisms, there is a risk of privacy violations [56,61,65], so ensuring compliance with data regulations is a key challenge [54,61].

A second major risk involves algorithmic bias and educational equity. The uneven distribution of AI resources can exacerbate the existing digital divide [51], as not all schools or students have equal access to the technology [41,53]. Simultaneously, inherent biases within AI models, such as gender bias, may lead to unfair outputs and evaluations, threatening educational fairness [60,61,70]. Third, significant challenges to academic integrity were noted, with the use of AI to generate assignments leading to widespread plagiarism [16,56,60] and “cheating automation” that is difficult to detect [16,56]. This is coupled with unresolved copyright disputes over AI-generated content [61,64]. Finally, the theme of job anxiety or replacement was noted among teachers [26,61]. However, many studies unanimously emphasized the irreplaceability of human teachers in providing emotional support [34,41], personalized guidance [41], and ethical criticism [38], roles that AI is not equipped to fulfill. For example, AI lacks the ability to express emotions and is unable to manage relational practices such as empathy and emotional understanding in teaching [37].

3.4.4. Implementation barriers

The final category of challenges relates to practical implementation barriers that hinder the effective integration of AI in teacher education. These barriers include infrastructure bottlenecks, where schools lack the necessary hardware or resources for ongoing maintenance and updates [40,47], a problem closely linked to the digital divide [51,54], which refers to disparities in access to digital technologies and in the skills needed to use them effectively [71]. A more prominent obstacle is the user capability gap, as preservice teachers often possess insufficient AI literacy [33,65,66], struggle with technical operations like prompt design [60], and experience technology-related anxiety [52], all of which necessitate significant additional training [67]. Furthermore, difficulties with systemic integration were widely reported, including structural conflicts between AI tools and traditional curricula [37] or evaluation methods [20], a lack of institutional support, and the absence of clear pathways for integrating technology into teaching practice [21,

64]. Lastly, the uncertainty of long-term effects was identified as a barrier, stemming from the limitations of existing research. Most studies are based on short-term interventions [27], and there is little evidence to verify whether skills developed in simulated environments successfully transfer to real classrooms [28], making sustainability evaluations challenging [52].

#### 4. Discussion

This scoping review synthesized 55 empirical studies to map the international landscape of AI applications in preservice teacher professional development, focusing on its characteristics, opportunities, and challenges. The findings provide a comprehensive overview that informs the field and highlights critical areas for future research.

##### 4.1. The evolving characteristics of AI integration in teacher education

Our first research question examined the characteristics of AI applications in teacher education. The findings reveal that AI has transitioned from being a peripheral tool to becoming deeply embedded across the continuum of teacher preparation. Within the included studies, AI is increasingly integrated as a support system for learning, practice, reflection, and innovation. This shift reflects a significant maturation from earlier iterations of educational technology, aligning with the vision of a more holistic partnership between humans and AI in education [72].

The strong use of GenAI in teacher education, particularly ChatGPT, reflects a practical trend toward accessible, low-threshold tools that offer immediate value in tasks like lesson planning and content creation. This aligns with broader observations about the rapid, practitioner-led adoption of GenAI in education [73]. However, the finding that many studies combine multiple technologies (e.g., GenAI with virtual simulations) suggests a more sophisticated goal: to create complex, multimodal learning environments. These low-risk trial and error spaces allow preservice teachers to engage in pedagogical simulations that would be difficult to replicate in real classrooms, offering a valuable new way for practice-based learning [74].

The current evidence base is also strongly concentrated in language and mathematics. These subjects are characterized by relatively well-defined rules, explicit representations, and clear problem-solving procedures, which align closely with the capabilities of many existing AI tools. However, this focus leaves an important gap. Our review identified limited empirical work on AI's role in supporting arts and humanities teachers' practice and professional development. To realize AI's broader educational potential, future research should also examine less structured domains such as the arts and humanities, where teaching and learning often involve interpretation, creativity, and engagement with complex ethical and socio-cultural issues. Systematic investigation is needed into how AI can meaningfully support these forms of practice without constraining the open-ended, dialogic, and value-laden nature of such disciplines.

##### 4.2. Opportunities: AI as a catalyst for preservice teachers' professional learning

Our second research question (RQ2) examined on the opportunities AI presents. Findings indicate that AI can enhance multiple facets of preservice teachers' professional competence—instructional design, subject teaching, practical training, teaching evaluation, reflective practice, and technology integration. A central theme is AI as a cognitive partner [75,76], augmenting preservice teachers' capabilities. This partnership is most evident in instructional design: by automating lower-order tasks (e.g., drafting lesson plans, resource searches), AI reduces extraneous cognitive load and enables teachers to focus on higher-order work such as pedagogical reasoning, creative problem solving, and in-depth learning activity design [77–79]. This aligns with

Luckin's view that AI can assume repeatable cognitive labor, freeing teachers for complex professional judgment [80]. Importantly, when using generative AI tools such as ChatGPT to support instructional design [56], preservice teachers engage in critical dialogue—evaluating and refining AI suggestions and connecting them to instructional theory—thus shifting from content deliverers to sophisticated educational designers. Accordingly, preservice teacher education should systematically incorporate human–AI collaborative design thinking, moving beyond traditional lesson-plan writing to explicit training in critically leveraging AI for inspiration and iterative solution development.

In subject teaching, AI provides highly contextualized support. In mathematics and science, AI can model expert problem-solving processes, creating a cognitive apprenticeship environment in line with Collins et al.'s study [81]. This helps make implicit disciplinary thinking (e.g., mathematical modeling, scientific reasoning) explicit and trainable [82,83]. In language education, AI-driven social context simulations (multi-role dialogues, culturally grounded interactions) support the development of pragmatic competence and teaching identity in low-risk settings, accelerating the shift from student to professional educator [40,41]. Compared to early drill-based software [84], AI's ability to simulate authentic social interaction is a key differentiator with substantial impact on teaching skills. Future language teacher education tools should therefore evolve from grammar-check utilities to realistic interaction platforms that prioritize communicative pedagogy. AI-driven virtual classrooms further enable a practice–feedback–iteration cycle. These scaffolded environments are vital for building professional skills that are difficult to develop under traditional constraints. Drawing on deliberate practice, virtual classrooms provide safe rehearsal opportunities and immediate, data-driven feedback essential for skill refinement [85]. Behavior-modeled AI “students” allow repeated practice of complex teaching behaviors while mitigating risks and resource limitations of live classrooms [30]. Unlike traditional video-based simulations [86], AI-enabled environments afford greater interactivity and personalization; immediate, multimodal feedback from AI tutors and AI-assisted video evidence [23,31] supports measurable improvement. These low-risk repetitions also bolster confidence and self-efficacy [27,29], consistent with Bandura's theory [87] that calibrated challenges build efficacy. The goal is not to replace real-world experience but to provide robust cognitive scaffolding. Future work should examine optimal integration pathways between AI simulations and human guidance to maximize readiness for clinical practice.

In teaching evaluation, AI is shifting preservice teachers' roles from evaluators to AI-augmented diagnostic designers and system optimizers. Automated grading reduces repetitive workload [24], allowing greater attention to diagnosing learning patterns and devising innovative assessment strategies. Beyond efficiency, AI-supported scoring can reduce human bias and enhance reliability; comparative analytics can also surface potential biases, driving self-correction and standard iteration [59]. Moreover, AI-generated, diverse item sets provide a cognitive scaffold that broadens and deepens assessment design, advancing evaluation literacy from skill imitation to professional creativity [88]. Training should move from discrete skills (e.g., scoring essays) toward AI-enhanced evaluation literacy: orchestrating AI for complex diagnosis, leveraging insights to optimize systems, and maintaining critical judgment in human–AI workflows.

AI also appears to deepen reflective and critical thinking. Consistent with Schön's reflective practitioner framework [89], AI tools supply the data structures and prompts needed to move from superficial reflection to analytic inquiry. Through transcript analysis and process visualization, platforms can render classroom interaction patterns visible [23], lowering the threshold for metacognitive monitoring and supporting reflection in action [89]. Notably, AI's imperfections—errors and biases—serve pedagogical purposes: they require preservice teachers to question, verify, and correct outputs, cultivating critical thinking and digital literacy aligned with Ennis's framework [90]. This practice hones information filtering and fosters a cautious stance toward technology,

essential for human–AI decision-making in teacher education.

Finally, AI reduces technical barriers and restructures TPACK. The critical use of AI across design, practice, and reflection catalyzes the maturation of technological pedagogical content knowledge, embedding technology within pedagogical reasoning rather than treating it as an add-on [91]. AI's mediating role brings TK, TPK, and TCK into closer, context-rich alignment, addressing challenges highlighted by Koehler and Mishra [91]. For example, in mathematics [21], dynamically generated function graphs (which belongs to TCK) prompt inquiry-based methods (TPK), strengthening integrated TPACK. In language teaching [50], chatbot-mediated personalization (which belongs to TCK) combined with designed instructional roles (TPK) creates new human–AI collaborative teaching pathways (TPACK). Thus, AI acts not as a simple add-on but as a catalyst for structural reorganization and deep integration within TPACK. Moving beyond a barriers-only perspective [92], our findings suggest a paradigm shift: preservice teachers develop the capacity to design and implement fundamentally innovative instruction, positioning them to meet the complex demands of future classrooms. Longitudinal research should track how AI-reconstructed TPACK influences early-career teaching performance.

#### 4.3. Challenges and risks of AI in preservice teachers' professional development

While the opportunities are promising, the challenges identified in this review (RQ3) are substantial and demand careful attention to ensure responsible, effective integration of AI in preservice teacher education. Four interconnected concerns emerged: technical limitations, the risk of over-reliance, ethical and social risks, and practical implementation barriers.

The technical limitations undermine pedagogical integrity. The unreliability of AI-generated content—factual errors, outdated information, and superficial analysis—increases preservice teachers' verification burden and risks modeling shallow inquiry [78]. This echoes Zawacki-Richter et al.'s study, who cautioned that automated solutions could obscure the complexity of education [93]. Moreover, frequent failures with non-English languages and nonverbal cues expose AI's limited sensitivity to the culturally situated, relational nature of teaching [94], resonating with Selwyn's (2019) critique that AI reduces teaching to technical transactions [95]. When systems cannot adapt to diverse cultural and linguistic contexts, they risk perpetuating a standardized, Anglocentric pedagogy that marginalizes diverse learners. Future development must prioritize cultural responsiveness and contextual awareness.

A second challenge is over-reliance, which may erode the core competencies teacher education seeks to cultivate. The ease of generating lesson plans or simulating interactions can deskill preservice teachers, diminishing creative autonomy and the development of practical wisdom (phronesis) gained through grappling with complex pedagogical problems [96]. The risk extends to K–12 students, whose cognitive autonomy may weaken if critical thinking is offloaded to AI, turning learners into instruction inputters rather than active knowledge constructors [97,98]. Consistent with Kirschner and De Bruyckere's study [99], easy access without guided effort can impair long-term learning and critical thinking. Instrumental rationality may replace the humanistic core of education, sidelining empathy and care [100]. Integration frameworks should therefore protect space for intellectual struggle and deep cognitive engagement for both teachers and students.

Third, the integration of AI raises ethical and social risks. Data privacy and algorithmic bias threaten equity; biased systems can reproduce or amplify inequalities related to race, gender, and socioeconomic status, creating what O'Neil calls "weapons of math destruction" [101]. Eubanks similarly demonstrated how algorithmic systems could entrench systemic discrimination; our findings confirm these risks in teacher education [102]. Programs must cultivate critical AI literacy so future teachers interrogate, rather than accept, algorithmic outputs—an

emphasis echoed by Miao et al. [103]. AI-generated content also intensifies academic integrity challenges, necessitating a shift from product-focused assessment to evaluating process, critical thinking, and originality [73]. Lodge et al. similarly advocated process-oriented assessment [104]. While job displacement anxieties persist, this review reaffirms that teachers' relational and ethical roles—mentoring, inspiring, and providing emotional support—remain uniquely human. Teacher education should embed these ethical dimensions to foster responsible AI use.

Finally, implementation barriers constrain scalable impact. Infrastructure deficits and gaps in user capability are primary obstacles. Many preservice teachers lack foundational AI literacy due to limited, systematic training within preparation programs [105–108], aligning with Ng et al., who argued that without embedded AI literacy, use remains superficial [106]. Structural frictions between generative AI and rigid curricula and assessments compound the problem, consistent with Selwyn's observations on institutional inertia [109]. Absent clear institutional supports and integration pathways, preservice teachers experiment in isolation, producing fragmented, surface-level use. Uncertainty about long-term effects—given a research base dominated by short-term, lab-based studies—further impedes sustainability. The field needs to move beyond proof-of-concept toward longitudinal research that examines lasting impacts on teacher development and student learning in authentic classroom settings.

#### 4.4. Implications, limitations, and future directions

This review has several important implications. For teacher education programs, it is no longer sufficient to teach about AI; programs must actively integrate AI into their pedagogy, modeling critical and effective use. Curricula should be redesigned to include AI literacy, data ethics, and the development of human-computer collaborative skills [110]. For policymakers, there is a clear need to invest in the infrastructure and professional development required for equitable AI integration and to establish clear ethical frameworks to guide its use [105].

While this study offers a comprehensive snapshot of the field, several limitations must be acknowledged, which in turn illuminate a clear path for future inquiry. The review's scope was confined to a systematic search of three academic databases over a five-year period, using specific search terms, exclusion criteria, and English-language publications, and access was limited to available subscriptions. As a result, this work cannot claim to be exhaustive or fully representative of all voices and authors writing about AI within preservice teacher education. Relevant research from other cultural and linguistic contexts, non-open-access venues, or studies indexed in alternative databases may have been omitted, and it is possible that different search terms and exclusion criteria would have yielded a different body of literature.

Given the rapid pace of technological change, this work also represents a snapshot in a quickly evolving field. Acknowledging these boundaries, future research must move beyond short-term interventions to include longitudinal studies that track the lasting impact of AI training on real-world classroom practice. Inquiry could also expand into underrepresented disciplines, such as the arts and humanities education, to develop a more holistic understanding of AI's potential [111]. A critical shift is needed towards investigating the nuanced dynamics of human-AI collaboration, focusing on how teachers make pedagogical decisions in partnership with intelligent systems. Finally, it is paramount to advance research on ethics, equity, and cross-cultural applications to develop practical frameworks for bias mitigation and ensure that AI integration is both globally relevant and locally sensitive. Pursuing these avenues will be essential for guiding the evolution of teacher education toward a future where AI and human educators work in a productive and ethical symbiosis to enrich learning for all students.

## 5. Conclusions

Based on the reviewed empirical studies, this scoping review establishes that artificial intelligence (AI) is a powerful, dual-edged force in the professional development of preservice teachers. On one hand, AI presents transformative opportunities, functioning as both a cognitive partner and a practice simulator. It can enhance the quality and efficiency of instructional design, provide data-driven feedback to sharpen reflective skills, and offer safe, simulated environments for honing practical teaching abilities. These applications have the potential to reshape teacher education by providing personalized, scalable, and evidence-based training pathways, thereby fostering a new generation of innovative and technologically adept educators.

On the other hand, the integration of AI in teacher education is accompanied by a complex web of challenges that warrant careful consideration. The technical limitations of current systems, including their propensity for error and bias, necessitate constant ongoing critical oversight. Furthermore, the risk of over-reliance on these technologies threatens to de-skill novice teachers and promote cognitive passivity. Significant ethical concerns surrounding data privacy, equity, and academic integrity also challenge the foundations of humanistic education. These findings highlight that technology is not a neutral tool; without careful stewardship, the promise of AI could be overshadowed by its perils. Ultimately, this review concludes that the successful integration of AI into teacher education demands a paradigm shift. This shift requires moving beyond simple technological adoption towards a model of critical, ethical, and pedagogically sound implementation that prioritizes human-centered learning and professional judgement.

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Research data can be shared upon request.

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## Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors only used ChatGPT in order to improve language, readability and organisation/flow of this article. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

## CRedit authorship contribution statement

**Liu Ziyang:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Hu Yongchun:** Writing – review & editing, Investigation, Data curation. **Zhang Qiaoping:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation.

## Declaration of competing interest

All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.caeo.2026.100330](https://doi.org/10.1016/j.caeo.2026.100330).

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