European Journal of Education Science

Vol. 2 No. 1 2026

Review **Open Access**

Innovative Models of Nursing Education in Higher Education Based on Knowledge Graphs: Review and Practice

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Received: 26 December 2025
Revised: 12 February 2026
Accepted: 24 February 2026
Published: 28 February 2026

Abstract: This review examines innovative models of nursing education in higher education, with a focus on the conceptual and practical integration of knowledge graphs to support teaching and learning. As nursing education faces increasing challenges arising from rapidly expanding knowledge systems and complex clinical environments, traditional pedagogical approaches often struggle to ensure coherence between theoretical instruction and clinical practice. Knowledge graphs, by structurally organizing nursing knowledge and explicitly representing relationships among concepts, offer new possibilities for curriculum design, personalized learning, and clinical training. This paper reviews recent studies on the application of knowledge graphs in nursing and health-related education, with particular attention to curriculum mapping, adaptive learning pathways, and clinical simulation. The potential benefits and limitations of these approaches are discussed in comparison with conventional educational models. In addition, the role of knowledge graphs in supporting interprofessional collaboration and lifelong learning in nursing education is explored. The review concludes by outlining future research directions, including the need for standardized knowledge graph frameworks and systematic evaluation of their educational impact. Overall, this study highlights the potential value of knowledge graphs as an enabling approach for advancing nursing education in higher education.

Keywords: Nursing Education; Knowledge Graphs; Higher Education; Curriculum Design; Personalized Learning; Clinical Simulation; Interprofessional Collaboration

1. Introduction

Nursing education in higher education is facing increasing pressure to respond to rapidly evolving healthcare systems, expanding medical knowledge, and growing expectations for clinical competence. Contemporary nurses are required not only to master extensive theoretical knowledge but also to apply this knowledge effectively in complex and dynamic clinical settings. However, traditional nursing education models often rely on linear curricula and fragmented content delivery, which can limit students' ability to integrate theoretical learning with clinical reasoning and decision-making. As a result, there is a growing demand for innovative educational models that support knowledge coherence, critical thinking, and learner-centered instruction.

In recent years, advances in educational technology have introduced new possibilities for addressing these challenges. Among these approaches, knowledge graphs have attracted increasing attention as a means of structuring and organizing complex domains of knowledge. By representing concepts as interconnected entities and explicitly modeling relationships among them, knowledge graphs provide a visual and logical

framework that supports knowledge exploration, integration, and reuse. In the context of nursing education, such representations align well with the discipline's emphasis on holistic understanding, clinical pathways, and evidence-based practice, offering potential advantages over traditional content-centered instructional designs [1].

Emerging research suggests that knowledge graphs can play a valuable role in curriculum design, personalized learning, and clinical training within nursing education. By mapping learning objectives, clinical competencies, and instructional content within a unified structure, knowledge-graph-based approaches may help reduce curricular fragmentation and enhance alignment between theory and practice. In addition, their integration with adaptive learning systems and simulation technologies offers opportunities to support individualized learning pathways and strengthen clinical reasoning skills. Despite this growing interest, existing studies remain dispersed across disciplines, and systematic discussions of how knowledge graphs can be meaningfully integrated into higher nursing education are still limited.

Against this background, the present review synthesizes recent research on knowledge-graph-based models in nursing and health-related education, with a focus on their educational roles, practical applications, and implementation challenges in higher education contexts. By examining curriculum design, personalized learning support, and clinical simulation from a knowledge graph perspective, this paper aims to clarify the potential contributions of this approach and to provide a conceptual foundation for future research and practice in innovative nursing education.

2. Structural Evolution of Nursing Education in Higher Education

Nursing education has evolved alongside the professionalization of healthcare and the increasing complexity of clinical practice. Early models of nursing education emphasized apprenticeship-based training, in which learning occurred primarily through observation and hands-on experience under the supervision of senior practitioners. Although this approach supported the development of practical skills, it relied heavily on implicit knowledge transfer and offered limited opportunities for systematic theoretical integration.

The subsequent emergence of hospital-based nursing schools introduced more structured forms of instruction, combining clinical training with foundational medical knowledge. These programs contributed to the standardization of nursing education and helped establish core professional competencies. However, hospital-centered models often prioritized service needs over educational coherence, resulting in fragmented curricula and insufficient integration between theoretical learning and clinical reasoning.

The incorporation of nursing education into higher education institutions marked a significant structural shift. University-based programs expanded the disciplinary scope of nursing education by integrating biomedical sciences, social sciences, and public health perspectives. This transformation strengthened the academic foundation of nursing and promoted critical thinking and evidence-based practice. At the same time, it substantially increased the volume and diversity of knowledge that students were required to manage, making traditional linear curricula and content-centered teaching approaches increasingly difficult to sustain.

In contemporary healthcare environments, nursing education has become highly knowledge-intensive and interdisciplinary. Nurses are expected to synthesize information from multiple domains, adapt to rapidly evolving clinical evidence, and collaborate effectively within interprofessional teams. Under these conditions, conventional instructional models often struggle to support meaningful knowledge integration and the transfer of learning from classroom settings to clinical practice. These structural challenges underscore the need for educational approaches that can organize complex nursing knowledge and make relationships among concepts explicit, thereby

laying the groundwork for innovative models such as knowledge-graph-based nursing education discussed in the following sections [2].

Despite these advances, existing structural models of nursing education continue to face persistent limitations. Many curricula remain organized around isolated courses and linear knowledge delivery, which makes it difficult for students to develop integrated clinical reasoning across domains. While digital learning platforms and simulation technologies have improved access to resources, they often function as supplementary tools rather than as coherent knowledge-organizing frameworks. As a result, students may acquire fragmented knowledge without a clear understanding of how theoretical concepts, clinical procedures, and decision-making processes are interconnected.

These challenges indicate a gap between the increasing complexity of nursing knowledge and the instructional structures used to support learning. There is a growing need for educational approaches that can explicitly represent relationships among concepts, support non-linear knowledge exploration, and align theoretical learning with clinical reasoning processes. This gap provides the structural and pedagogical rationale for exploring knowledge graph–based models in nursing education, which are examined in the subsequent sections.

3. Knowledge Graph–Based Curriculum Design in Nursing Education

Knowledge graph–based curriculum design emphasizes the structured organization and integration of nursing knowledge to support competency-oriented education. Nursing education requires the continuous integration of theoretical knowledge, clinical skills, and context-dependent clinical decision-making, which poses particular challenges for traditional linear curriculum structures. Rather than serving merely as a technical data structure, the knowledge graph functions as a pedagogical tool that reveals the relationships among theoretical knowledge, clinical skills, and learning outcomes, thereby facilitating coherent curriculum planning and instructional alignment.

3.1. Pedagogical Principles of Knowledge Graph Construction

In nursing education, the construction of knowledge graphs must prioritize pedagogical relevance over purely technical considerations. Core nursing concepts—such as diseases, symptoms, interventions, and clinical procedures—are modeled as interconnected entities to mirror authentic clinical reasoning processes. The relationships between these entities represent clinically meaningful associations, including symptom manifestation, intervention rationale, and care pathways. This structure facilitates the explicit representation of how foundational knowledge supports advanced clinical competencies.

The design of the knowledge graph is fundamentally driven by clearly defined educational objectives, ensuring that its framework supports competency development and clinical decision-making skills. By explicitly mapping dependencies and hierarchies among concepts, knowledge graphs provide a scaffold that aligns with students' cognitive development stages and promotes effective learning sequences.

From an instructional design perspective, knowledge graph construction in nursing education typically follows a multi-layered structure. At the conceptual layer, core nursing knowledge units—such as diseases, symptoms, interventions, and care outcomes—are defined as entities. At the relational layer, clinically meaningful associations, including causal, temporal, and procedural relationships, are encoded to reflect authentic nursing workflows. Beyond knowledge representation, a pedagogical layer maps curriculum objectives, learning activities, and assessment tasks onto the graph structure. This mapping ensures explicit alignment between instructional content and competency development, supporting progressive skill acquisition. At the reasoning layer, graph-based inference mechanisms support clinical decision-making tasks, allowing

students to explore care pathways, compare intervention strategies, and evaluate potential outcomes within simulated scenarios [3].

From a cognitive science perspective, knowledge graphs help organize and integrate complex information, facilitating knowledge transfer while reducing cognitive load. This clarity enables learners to construct mental models that more accurately reflect real-world clinical reasoning.

Moreover, knowledge graphs are dynamic entities requiring continuous updates to incorporate evolving clinical guidelines, evidence-based practices, and nursing standards. Maintaining the relevance and scientific accuracy of educational content necessitates ongoing interdisciplinary collaboration between nursing educators and data specialists. This collaboration ensures a balance between clinical validity and computational feasibility, leveraging advances in semantic web technologies, natural language processing, and machine learning to automate and refine graph construction. Such integration enhances both the pedagogical value and technological robustness of knowledge graphs in nursing education.

3.2. Knowledge Graphs for Curriculum Mapping and Alignment

Knowledge graphs offer a powerful framework for curriculum mapping by visually representing the relationships among learning objectives, instructional content, and assessment methods. This interconnected structure enables educators to evaluate how well the curriculum supports desired competencies and identify potential gaps where learning objectives may be underrepresented or insufficiently assessed. By aligning curriculum components within a knowledge graph, educators gain a systematic tool for ensuring coherence and comprehensiveness in nursing education programs. This approach facilitates continuous curriculum evaluation and refinement, promoting an outcome-based educational model that responds effectively to evolving clinical requirements [4].

Furthermore, knowledge graph–based curriculum mapping enhances transparency and communication among faculty, enabling collaborative curriculum development and alignment across courses and modules. It also supports personalized learning by clarifying prerequisite knowledge and guiding the sequencing of content to match students' developmental needs and learning progressions.

3.3. Practical Implementation in Nursing Education Contexts

Existing studies and pilot projects reported in the broader field of medical and health professions education indicate that knowledge graph–based approaches have been increasingly explored to support curriculum organization and clinical learning. Although large-scale implementations in nursing education remain limited, several peer-reviewed studies have demonstrated the feasibility of applying knowledge graphs to structure clinical knowledge, support scenario-based learning, and enhance clinical reasoning skills.

In reported implementations, knowledge graphs are commonly used to integrate diseases, symptoms, nursing interventions, and clinical outcomes into unified semantic frameworks. These frameworks are embedded within digital learning platforms or simulation systems, allowing students to navigate complex clinical relationships and engage in problem-oriented learning tasks. Such implementations have been shown to improve conceptual clarity and support the integration of theoretical knowledge with clinical decision-making processes, particularly in areas such as disease management and care planning [5].

Evidence from related medical education studies suggests that knowledge graph–supported learning environments can enhance students' diagnostic accuracy, reasoning efficiency, and engagement in simulated clinical scenarios. While quantitative outcomes vary across studies, qualitative findings consistently highlight improved understanding

of clinical logic and stronger connections between foundational knowledge and practical application.

Despite these promising results, the practical implementation of knowledge graph–based curricula in nursing education is still at an early stage. Challenges include the lack of standardized nursing knowledge ontologies, the need for interdisciplinary collaboration between educators and technical experts, and the resources required for system development and maintenance. Nevertheless, the adaptability of knowledge graph frameworks allows them to evolve alongside updates in clinical guidelines and educational objectives, making them a viable foundation for future curriculum innovation and continuous professional development in nursing education.

4. Personalized Learning Pathways

4.1. Enhancing Clinical Simulation

Knowledge graphs significantly enhance clinical simulation by modeling the complex relationships among patient data, symptoms, diagnoses, and nursing interventions. Unlike traditional branching scenarios, knowledge graph–based simulations allow dynamic and adaptive interactions, where changes in one clinical parameter can propagate and influence other related factors in real time. For example, adjusting medication dosage can affect vital signs such as heart rate and blood pressure, creating a more realistic and immersive learning environment.

This dynamic modeling supports the development of students' clinical reasoning and decision-making skills by providing immediate feedback on the consequences of their actions within a safe, controlled setting. Furthermore, knowledge graph–driven simulations facilitate exposure to a wide range of clinical scenarios, including rare or complex cases that students might not encounter during clinical rotations, thereby broadening their experience and readiness for real-world practice [6].

Despite these advantages, implementing knowledge graph–based clinical simulations requires significant collaboration between nursing educators and technical experts, as well as adequate resources to develop and maintain the simulation platforms.

The knowledge graph is not merely a tool but serves as the central framework within nursing education, connecting learning data, instructional content, and assessment mechanisms. Through this architecture, students' learning paths, clinical simulations, and evaluations are seamlessly integrated, forming a highly coordinated educational system. By dynamically adjusting and providing feedback, the knowledge graph ensures that each step in the learning process aligns with individual student needs and real-world clinical contexts, enhancing the overall coherence and applicability of the educational experience.

4.2. Personalized Learning Pathways

Knowledge graphs enable the creation of personalized learning pathways by dynamically assessing each student's existing knowledge and identifying gaps. Personalization in this context is based on rule-based or graph-based models, rather than black-box AI systems. By mapping core nursing concepts and competencies within the graph, adaptive learning systems can customize educational content, resources, and assessments to address individual needs. For example, if a student struggles with cardiovascular physiology, the system may recommend supplementary materials such as interactive simulations or targeted exercises to reinforce understanding in that area.

In addition, analysis of student interactions with the knowledge graph—such as accessed topics, time spent, and assessment outcomes—provides valuable insights into individual learning preferences and styles. This data-driven approach supports the customization of learning modalities, offering visual, auditory, or kinesthetic resources aligned with each learner's preferences, thereby enhancing engagement and comprehension.

Table 1 summarizes typical associations between learning styles, knowledge graph–based performance metrics, and corresponding personalization strategies. This framework guides the development of adaptive learning pathways tailored to optimize individual student outcomes.

Table 1. Associations Between Learning Styles, KG-Based Performance Metrics, and Personalization Strategies.

Learning Style	KG-Based Performance Metric	Personalization Strategy
Visual Learner	Frequent access to visual resources	Recommend videos, diagrams, and infographics
Auditory Learner	High engagement with audio materials	Prioritize podcasts, lectures, and discussions
Kinesthetic Learner	Preference for simulations and exercises	Provide interactive simulations and hands-on tasks
Strength in Domain	High accuracy and speed in domain nodes	Offer advanced content and challenges
Weakness in Domain	Low performance in specific domain nodes	Provide targeted remediation and scaffolding

4.3. Creating Customized Learning Experiences

Knowledge graphs enable highly customized learning experiences by integrating individual students' prior knowledge, learning preferences, and career goals into a cohesive framework. This framework guides the adaptive selection of learning materials, dynamic assessments, and personalized feedback, all tailored to address individual needs. As students progress, assessments target knowledge gaps and provide focused evaluations, while feedback addresses specific misconceptions, driving continuous improvement.

The adaptive nature of knowledge graphs adjusts content difficulty and assessment complexity based on student performance, ensuring an optimal balance of challenge and engagement. This promotes deeper comprehension and sustained motivation, supporting efficient learning progression and competency development.

In addition to immediate educational benefits, knowledge graphs facilitate longitudinal tracking of student growth. This allows both educators and learners to visualize learning trajectories, enabling informed decisions regarding future learning paths. Effective implementation requires robust data management, interdisciplinary collaboration, and careful consideration of ethical concerns, such as privacy and fairness.

By integrating customization, tracking, and feedback into a cohesive "learning cycle," knowledge graphs foster continuous formative assessment and competency development. This cycle ensures that learning content dynamically adapts to meet individual needs, promoting progressive skill acquisition and professional readiness. As students engage with adaptive pathways, their strengths and weaknesses are constantly monitored, enabling timely feedback and interventions. Ultimately, this dynamic feedback loop enhances not only academic growth but also critical thinking and clinical decision-making skills, preparing students for real-world clinical challenges.

Recent research demonstrates the practical application of knowledge graphs in nursing education. For example, in a Surgical Nursing micro-course study, knowledge graphs were used to organize nursing knowledge into a structured framework, supporting personalized learning paths. Students reported increased engagement and better problem-solving abilities. Additionally, studies in flipped classrooms combined with knowledge graphs showed that students experienced improved learning autonomy and clinical decision-making skills.

5. Knowledge Graphs in Clinical Simulation and Decision-Making

Knowledge graphs play a crucial role in advancing clinical simulation and decision-making within nursing education. By structuring and interlinking medical knowledge, patient data, and treatment protocols, they provide a dynamic and comprehensive framework to support clinical reasoning, simulate complex scenarios, and facilitate evidence-based practice.

5.1. Enhancing Clinical Reasoning

Knowledge graphs enhance clinical reasoning by offering quick access to interconnected medical information, including disease symptoms, diagnostic criteria, and treatment options essential for accurate clinical assessment. By explicitly mapping relationships between medical concepts, these graphs enable students to systematically explore potential diagnoses based on patient symptoms and histories, promoting structured critical thinking [7].

For example, the system can support the exploration of conditional probabilities such as P(D|S)—the likelihood of disease D given symptom S—helping learners develop probabilistic diagnostic skills. This structured approach not only strengthens clinical judgment but also improves decision-making quality, ultimately contributing to better patient outcomes. The benefits of knowledge graphs in enhancing clinical reasoning are summarized in Table 2. These features collectively improve the accessibility of complex medical information, support diagnostic accuracy through mapped relationships, promote critical thinking, and ultimately contribute to better-informed clinical decisions and improved patient outcomes.

Table 2. Improved Clinical Reasoning Using Knowledge Graphs.

Feature	Benefit
Readily Accessible Knowledge	Facilitates quick retrieval of interconnected medical information (e.g., disease symptoms, diagnostic criteria, treatment options).
Enhanced Diagnostic Support	Maps relationships between medical concepts to support exploration of potential diagnoses based on symptoms and patient history. Enables exploration of $P(D\|S)$(probability of disease D given symptom S).
Critical Thinking Development	Promotes a structured approach to learning, fostering critical thinking skills.
Informed Clinical Decisions	Improves the ability to make well-informed clinical decisions based on relevant medical knowledge.
Improved Patient Outcomes	Ultimately contributes to better patient outcomes through more accurate assessments and treatments.

5.2. Simulating Complex Clinical Scenarios

Knowledge graphs offer a powerful and flexible framework for simulating complex clinical scenarios by representing the intricate interconnections among medical concepts, patient-specific data, and treatment protocols. Unlike traditional simulation models that often rely on fixed branching logic, knowledge graph–based simulations dynamically adjust in response to learners' decisions, creating a more realistic and immersive training environment.

For example, when a student modifies a medication dosage (d) within the simulation, the system can automatically propagate the effects through related physiological parameters such as heart rate (h), blood pressure (b), and oxygen saturation. These interdependent variables, modeled as nodes and edges in the knowledge graph, reflect the cascading consequences of clinical interventions, thereby exposing students to the multifaceted nature of patient management.

This real-time adaptability allows simulations to present personalized challenges tailored to each learner's knowledge and decision-making skills. Students can explore multiple clinical pathways, observe outcomes, and refine their reasoning in a safe, controlled setting. Ultimately, such simulations enhance critical thinking, clinical judgment, and preparedness for the unpredictability of real-world healthcare environments [8].

5.3. Supporting Evidence-Based Practice

Knowledge graphs significantly improve the implementation of evidence-based practice (EBP) by efficiently organizing and synthesizing large volumes of clinical research, guidelines, and patient outcome data. Through semantic relationships among diseases, treatments, and clinical results, these graphs enable nursing students to navigate complex medical knowledge systematically and identify the most relevant and up-to-date evidence [9].

Students can query the knowledge graph to retrieve current research findings that support specific interventions, allowing for informed and scientifically grounded clinical decision-making. This expedited access to synthesized knowledge bridges the traditional gap between research and practice, empowering students to apply the latest evidence in patient care confidently.

Moreover, the use of knowledge graphs fosters a culture of inquiry and lifelong learning. By encouraging critical appraisal of evidence and continuous updating of clinical knowledge, nursing education can produce practitioners who remain adaptable and proficient in evolving healthcare landscapes.

6. Comparison and Challenges

6.1. Benefits of Knowledge Graph Integration

The integration of knowledge graphs into nursing education offers multiple, significant benefits. Primarily, it enhances student engagement by providing interactive and personalized learning experiences. Unlike traditional rote memorization, knowledge graphs facilitate the exploration of interconnected nursing concepts, enabling learners to grasp complex relationships within medical knowledge more intuitively and deeply.

Furthermore, learning outcomes are improved as students develop a holistic understanding of nursing knowledge. This comprehensive view supports informed clinical decision-making by allowing learners to visualize the intricate relationships among diseases, symptoms, treatments, and nursing interventions. Such visualization fosters the development of critical thinking skills essential for effective practice [10].

Another major advantage lies in the enhancement of clinical competence through the application of knowledge graphs in simulated clinical scenarios. Students gain rapid access to relevant, interconnected information, improving diagnostic accuracy and problem-solving capabilities in a safe, controlled environment. This experiential learning bridges the gap between theoretical knowledge and practical application, ultimately contributing to improved patient care quality.

Overall, knowledge graphs promote a more efficient and effective transfer of knowledge, equipping nursing students with the cognitive tools necessary for navigating complex healthcare environments.

6.2. Challenges and Limitations

Despite these benefits, the implementation of knowledge graphs in nursing education faces several challenges and limitations. One of the most significant obstacles is data integration. Nursing education draws from diverse data sources—including electronic health records, academic research, clinical guidelines, and curricular materials—which often vary in terminology, format, and granularity. Harmonizing these heterogeneous sources into a coherent, interoperable knowledge graph requires substantial effort and domain expertise.

In addition, the initial investment in infrastructure can be prohibitive, particularly for institutions with limited financial resources. Costs associated with software licensing, hardware procurement, and specialist consultations may hinder widespread adoption [11].

Moreover, the successful use of knowledge graphs depends heavily on faculty competency. Educators must acquire skills in semantic web technologies, ontology development, data modeling, and query languages such as SPARQL. This necessitates dedicated training programs and ongoing professional development to build the necessary technical and pedagogical expertise.

Addressing these challenges through strategic planning, interdisciplinary collaboration, and investment in faculty development is critical for realizing the transformative potential of knowledge graphs in nursing education.

7. Future Perspectives

7.1. Emerging Trends and Technologies

The future application of knowledge graphs in nursing education is closely linked with rapid advancements in artificial intelligence (AI) and related technologies. Machine learning techniques hold promise for automating the construction and continual updating of knowledge graphs by extracting relevant information from diverse and ever-expanding data sources. This automation reduces manual workload while enhancing the accuracy and comprehensiveness of the knowledge base.

Natural language processing (NLP) technologies are poised to revolutionize user interaction with knowledge graphs, enabling learners and educators to query complex clinical and educational content using natural language. Such intuitive interfaces can provide personalized, context-aware responses, significantly improving accessibility and user experience.

Moreover, AI-driven adaptive learning systems can leverage knowledge graphs to tailor educational content dynamically, aligning learning pathways with individual students' knowledge gaps, preferences, and cognitive styles. This personalization has the potential to significantly boost learning efficiency and effectiveness, with preliminary studies suggesting measurable improvements in student performance [12].

7.2. Research Directions

Future research should focus on conducting rigorous longitudinal studies to evaluate the long-term impact of knowledge graph–enhanced nursing curricula on clinical competencies and patient care outcomes. Understanding the relationship between knowledge graph usage during education and metrics such as clinical error reduction or patient satisfaction will provide valuable evidence of effectiveness.

Additionally, research is needed to assess the scalability and adaptability of knowledge graph–based educational models across diverse healthcare settings, cultural contexts, and learner populations, taking into account variations in sample sizes and implementation timelines.

Ethical considerations surrounding the use of data-driven insights derived from knowledge graphs also warrant careful examination. Issues such as data privacy, algorithmic transparency, and potential biases must be addressed to ensure responsible integration of these technologies into nursing education and practice.

8. Conclusion

Knowledge graphs represent a transformative approach to nursing education by structuring complex medical knowledge into accessible, interconnected frameworks that enhance curriculum design, personalized learning, and clinical decision-making. Their integration fosters deeper understanding, critical thinking, and practical competence among nursing students, bridging the gap between theory and clinical practice.

Despite challenges related to data integration, infrastructure, and faculty training, the benefits of knowledge graphs are substantial and far-reaching. To effectively implement knowledge graphs, nursing institutions should adopt a phased approach: beginning with pilot programs to test and refine the system before scaling to broader use. Investment in technology infrastructure and faculty training is crucial to ensure smooth integration into existing curricula. Collaborative efforts between data scientists, educators, and healthcare professionals will further enhance the relevance and effectiveness of the system.

Continued technological advancements and targeted research will further unlock their potential, enabling more adaptive, evidence-based, and learner-centered nursing education. By embracing these innovations, nursing education can better prepare practitioners to meet the demands of an increasingly complex healthcare landscape, ultimately improving patient outcomes and advancing the profession.

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