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Artificial Intelligence-Empowered Zoology Teaching in Higher Education: Pathways and Practical Strategies

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ABSTRACT

This study explores how artificial intelligence is reshaping higher education zoology by moving beyond digitization toward an intelligent educational ecosystem. Zoology faces challenges of expanding knowledge, complex practical training, and diverse student backgrounds. Through systematic review and comparative analysis of artificial intelligence applications---including augmented reality, intelligent identification, virtual teaching platforms, and knowledge graphs---this study develops a focused theoretical framework centered on two interconnected pillars: the Three-Tier Competency Development Model (cognitive enhancement, skill transfer, value internalization) and the Pedagogical Architecture (large language models as cognitive tools, knowledge graphs as infrastructure, intelligent agents as interfaces). The findings trace an evolutionary trajectory from technological embedding to ecological reconstruction, emphasizing the balance between explicit and tacit knowledge. Unlike previous reviews, this study provides actionable strategies for curriculum design, teaching facilitation, assessment, and institutional support. Artificial intelligence's role is not merely efficiency gain but reshaping the educational landscape by harmonizing technological assistance with embodied learning. This overview prepares readers for the detailed model and architecture presented in the full text.

Keywords: artificial intelligence, zoology teaching, large language model, knowledge graph, tacit knowledge, paradigm shift

Introduction

The integration of artificial intelligence into higher education marks a paradigm shift from digitization to intelligent transformation. As Jin[1] articulates, AI is igniting the "new quality engine" of higher education, fundamentally reshaping the pedagogical landscape. This transformation is especially consequential for zoology---a discipline that uniquely bridges classical descriptive knowledge with modern experimental methodologies.[2-6] Zoology education faces three inherent challenges: the exponential growth of knowledge in the life sciences, the complexity of integrating theoretical learning with practical fieldwork, and the diverse learning needs of students from varying academic backgrounds.[7,8]

Traditional approaches to educational technology often fall into the trap of technological instrumentalism, treating AI merely as a more efficient means of delivering existing content. However, the true potential of AI lies in its capacity to reconstruct the entire knowledge ecology of zoology education. This reconceptualization requires moving beyond simplistic notions of "AI in education" toward a deeper understanding of how intelligent systems can mediate the relationship between learners and the biological world.

The urgency of this pedagogical transformation is underscored by the rapid advancement of intelligent animal husbandry and related industries. As Zhao[9] notes, the development trends of intelligent animal husbandry in China present both opportunities and challenges for talent cultivation. Similarly, the Ministry of Agriculture and Rural Affairs[10] has documented the accelerating integration of AI technologies in livestock management, veterinary practice, and wildlife conservation. These professional demands necessitate a corresponding evolution in zoology education.

Accordingly, this study seeks to achieve three objectives: first, to systematically review current AI applications in zoology and related life sciences education; second, to develop a theoretical framework for understanding AI's role in knowledge construction; and third, to propose practical strategies for implementing AI empowered zoology teaching. By synthesizing insights from diverse cases—including augmented reality anatomy, intelligent species recognition, virtual teaching platforms, and knowledge graph applications—the author seeks to establish both conceptual foundations and actionable pathways for educators navigating this transformation.

Core Theme One: The Three-Tier Competency Development Model

Based on a synthesis of existing applications (including augmented reality anatomy[11], intelligent species recognition[12], and virtual teaching platforms[13]) and theoretical considerations, this study proposes the **Three-Tier Competency Development Model** as the first core pillar. This model encompasses cognitive enhancement, skill transfer, and value internalization as interconnected dimensions of learning. Cognitive load theory provides a foundational lens for understanding how artificial intelligence can optimize instructional design[14,15].

TIER 1: COGNITIVE ENHANCEMENT

The first tier focuses on using artificial intelligence to enhance students' cognitive engagement with zoological knowledge. Vertical domain-specific large language models serve as cognitive tools that can engage students in Socratic dialogue about evolutionary adaptations, guide them through taxonomic reasoning, and provide immediate feedback.[16-19] Augmented reality applications, such as those developed by Jiang et al[11], provide visual-cognitive support by enabling students to manipulate three-dimensional representations of anatomical structures. This spatial visualization supports the development of mental models essential for expert performance.

TIER 2: SKILL TRANSFER

The second tier addresses the challenge of transferring knowledge from classroom contexts to practical applications. Intelligent recognition systems, building on architectures like YOLOv5 and convolutional neural networks[12], enable students to practice species identification in authentic contexts. Virtual teaching offices[13] create spaces where students can engage with simulated cases requiring application of zoological knowledge to real-world problems. The industry-education integration emphasized by the China Association of Higher Education[20] and Zeng et al[21] is particularly relevant here, ensuring that skills developed through artificial intelligence align with professional demands.

TIER 3: VALUE INTERNALIZATION

The third tier concerns the internalization of professional values and ethical frameworks. Artificial intelligence systems can support this by presenting ethical dilemmas, providing multiple perspectives on controversial issues, and connecting individual actions to broader consequences.[22,23] However, value internalization ultimately requires embodied experience. As the Chinese Association of Animal Science and Veterinary Medicine[24] notes, direct engagement with animals and ecosystems remains essential for developing tacit knowledge. Artificial intelligence should augment, not replace, these experiences.

Core Theme Two: Pedagogical Architecture and Implementation Pathways

Implementing the Three-Tier Model requires a coherent pedagogical architecture as the second core pillar. We propose an architecture with three interconnected components: vertical domain-specific large language models as cognitive tools, knowledge graphs as infrastructure, and intelligent agents as interaction interfaces. Recent meta-analyses confirm that AI-powered chatbots can significantly enhance science education when integrated thoughtfully[25].

VERTICAL DOMAIN-SPECIFIC LARGE LANGUAGE MODELS AS COGNITIVE TOOLS

Generic large language models lack specialized knowledge for accurate zoology education. Vertical domain models trained on curated zoological literature, taxonomic databases, and anatomical atlases are essential. Such models can serve as Socratic interlocutors, explainers, and coaches. The convergence of pedagogical approaches noted by Yuan and Hu[26] suggests these functions should be integrated within coherent learning experiences.

KNOWLEDGE GRAPHS AS INFRASTRUCTURE

Knowledge graphs[27-29] provide the underlying infrastructure that ensures artificial intelligence interactions are grounded in accurate, structured domain knowledge. A comprehensive zoology knowledge graph would represent taxonomic relationships, morphological features, physiological processes, ecological interactions, evolutionary relationships, and practical applications. This structured representation enables artificial intelligence systems to navigate the conceptual space of zoology intelligently.

INTELLIGENT AGENTS AS INTERACTION INTERFACES

Intelligent agents provide the interface through which students interact with artificial intelligence capabilities. The smart platforms developed by Shandong University[13] exemplify integration of multiple capabilities within coherent user experiences. For zoology, agents might be specialized for different contexts: a field guide agent for outdoor use, a laboratory agent focused on experimental protocols, and a classroom agent supporting collaborative problem-solving.

Pathways from Technological Embedding to Ecological Reconstruction

Based on the theoretical framework and case analyses, we propose four categories of actionable strategies for educators implementing AI-empowered zoology teaching. Each category includes specific, stepwise actions.

CURRICULUM DESIGN STRATEGIES

Curriculum design should balance AI-enhanced learning with embodied experience using the

Three-Tier Model by following progressive complexity: in foundational courses, use AI for basic cognitive support (e.g., terminology, taxonomy); in intermediate courses, shift to skill-transfer applications (e.g., virtual dissection, species identification); in capstone courses, engage students with value-laden ethical scenarios (e.g., AI-assisted wildlife conservation decisions). Additionally, educators must map AI-enhanced learning outcomes directly to professional competencies from the Chinese Veterinary Medical Association[30] and industry reports[10], creating a checklist for each course. To ensure cross-course coherence, use knowledge graphs[29] to link concepts across courses---for example, connect anatomy of a species in Course A to its physiology in Course B---and provide students with a visual concept map at the start of each module.

TEACHING AND FACILITATION STRATEGIES

Effective teaching with AI requires developing new facilitation skills: orchestrate human-AI collaboration by designing activities where students first solve a problem manually, then compare their solution with AI output, and finally justify when to trust AI suggestions versus their own judgment, mirroring professional practice[9]. Support metacognitive development using reflection prompts such as "What did the AI miss? What did you add? What would you do differently next time?" and require a brief "AI interaction log" for each assignment. Crucially, preserve embodied learning by never replacing direct animal or ecosystem engagement with AI; for every AI-based activity (e.g., AR anatomy[11]), schedule a corresponding hands-on session (e.g., actual dissection or field observation), following the "1:1 rule" – one AI activity, one real experience.

ASSESSMENT STRATEGIES

Assessment must evolve to capture learning outcomes in AI-empowered environments through process-oriented evaluation: assess not only final answers but also how students interacted with AI tools (e.g., prompts used, revisions made); Liu et al[31] provide examples of process rubrics. Design authentic tasks that mirror professional practice, such as case-based assessments from the Steering Committee of Animal Production Majors[32]---for example, "Given a set of animal images and an AI classifier, identify misclassifications and explain why the AI might have erred." Finally, implement collaborative assessment by assigning group tasks where students divide roles (e.g., one uses AI, another verifies with a field guide, a third synthesizes), and assess both the product and the team process.

INSTITUTIONAL SUPPORT STRATEGIES

Institutional support is essential for sustainable implementation: invest in smart teaching platforms[13] and discipline-specific knowledge graphs[29], following the "AI4SEU" initiative[33] as a benchmark by allocating dedicated budget for hardware, software, and technical support. Provide ongoing faculty development through quarterly workshops on AI pedagogy (not just tool training) and create a peer-observation program where faculty share effective AI-integrated lessons. Finally, establish formal industry partnerships with intelligent animal husbandry companies, veterinary AI startups, and similar entities to co-design curricula and offer student internships, using mechanisms from the China Association of Higher Education[20] as a template.

Discussion

THE BALANCE BETWEEN CODIFIED AND TACIT KNOWLEDGE

A central contribution of this study is the recognition that AI's role in zoology education must be understood in relation to the balance between codified and tacit knowledge. Codified knowledge---explicitly stated in texts, lectures, and databases---is what AI systems excel at transmitting. Tacit knowledge---the embodied understanding that comes from direct experience with animals and ecosystems---remains fundamentally human.

The danger of AI integration is that efficiency gains in transmitting codified knowledge may crowd out opportunities for developing tacit knowledge. If students spend more time with augmented reality anatomy[11] and less time in actual dissection, they may miss the embodied understanding that comes from direct manipulation. If intelligent recognition systems[12] make field identification effortless, students may never develop the perceptual skills that underpin expert observation.

The solution is not to reject AI but to deliberately design learning environments that maintain the balance. The Three-Tier Model's emphasis on value internalization recognizes that certain forms of knowing require embodied experience. The pedagogical architecture's integration of multiple AI capabilities allows for flexible deployment that preserves hands-on engagement while enhancing cognitive support.

IMPLICATIONS FOR TEACHER ROLES

As AI assumes more of the cognitive scaffolding functions traditionally performed by teachers, educator roles must evolve. Teachers become less dispensers of information and more designers of learning experiences, orchestrators of human-AI collaboration, and mentors supporting value internalization.[34-37]

This evolution requires new competencies. Teachers must understand AI capabilities and limitations well enough to design appropriate learning activities. They must be able to interpret AI-generated analytics about student progress and intervene appropriately. Most importantly, they must model the professional judgment that integrates AI assistance with human values.

The symposium summary from the Chinese Association of Animal Science and Veterinary Medicine[24] recognizes this shift, noting that anatomy teaching reform must address not only what students learn but also how teachers facilitate learning. Similarly, Zeng et al[21] emphasize that digital intelligence reform requires corresponding evolution in teaching practices.

LIMITATIONS AND FUTURE RESEARCH

This study has several limitations that suggest directions for future research. First, as a conceptual and theoretical review, it does not present empirical data on the effectiveness of the proposed model. Future research should implement and evaluate the Three-Tier Model in diverse zoology education contexts.

Second, the rapid pace of AI development means that specific technologies discussed here (e.g., particular CNN architectures) may become obsolete quickly. The theoretical framework, however, is intended to remain relevant across technological generations by focusing on fundamental pedagogical relationships rather than specific implementations.

Third, the integration of AI into zoology education raises ethical questions that deserve deeper exploration. How does AI-mediated learning affect students' relationships with animals? What are the equity implications of differential access to AI technologies? How should assessment practices evolve to maintain fairness when students have varying access to AI tools? These questions require collaborative investigation by educators, ethicists, and technologists.

Conclusion

This study has explored pathways for artificial intelligence-empowered zoology teaching by developing two core pillars: the Three-Tier Competency Development Model (cognitive enhancement, skill transfer, value internalization) and the Pedagogical Architecture (large language models, knowledge graphs, intelligent agents). The evolutionary trajectory from technological embedding to ecological reconstruction reveals that artificial intelligence's fundamental mission is reshaping the equilibrium between explicit and implicit knowledge, harmonizing technological assistance with embodied experience.

The ultimate success of artificial intelligence-empowered zoology teaching will be measured not by efficiency metrics alone, but by whether it produces graduates who combine deep biological understanding with professional judgment, ethical commitment, and the ability to work effectively with intelligent systems. Achieving this vision requires continued collaboration among educators, technologists, and industry partners, guided by shared commitment to educational excellence and respect for the living world.

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Author Contributions:

Maoxian Wang conceptualized the study, conducted the literature review and case analyses, developed the theoretical framework and pedagogical model, and wrote and revised the entire manuscript.

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