

Practical Challenges and Optimization Pathways for Industry-Education Integration in Application-Oriented Universities in the Digital Era

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Abstract: In the context of the digital era, industry-education integration in application-oriented universities is undergoing significant transformation. This study conducts a multidimensional deconstruction of such integration using the Technology-Organization-Environment (TOE) framework. Throughout the digital transformation process, challenges persist across various dimensions: technologically, characterized by inadequate digital infrastructure and the prevalence of "data silos"; organizationally, reflected in rigid multi-stakeholder collaboration, sluggish reorganization of operational processes, and inefficient resource integration; and environmentally, evidenced by policy implementation gaps, insufficient market support, and misalignment with societal needs. Consequently, it is imperative to establish a collaborative virtual-physical integrated space platform-based, leverage data as the vital link to streamline the flow of essential elements, reshape multi-stakeholder coordination mechanisms through governance frameworks, revamp talent development systems with curricula at the core, and energize innovation momentum via faculty development. By reconstructing key elements, harnessing technological empowerment, reorganizing structures, and optimizing the environment, this system facilitates the digital transformation and high-quality development of industry-education integration, providing theoretical insights and practical pathways for cultivating application-oriented talents suited to the digital age.

Keywords: Digital Era; Application-Oriented Universities; Industry-Education Integration; Toe Framework; Practical System.

1. Introduction

Driven by digital technologies, the ongoing wave of scientific and technological revolution and industrial transformation is reshaping the global economic structure[1-2], emerging as a strategic cornerstone for advancing new-type industrialization and building a "Digital China". This paradigm shift imposes unprecedented demands on the human resource ecosystem, urgently calling for a contingent of interdisciplinary "digital talents" who master core digital technologies and possess a profound understanding of industrial operation laws[3]. According to the 2023 "Research Report on Industrial Digital Talents", China faces a digital talent gap of 25–30 million, with structural mismatches between supply and demand becoming increasingly acute. As pivotal platforms bridging cutting-edge academic research and industrial practice, applied universities bear the dual mission of cultivating high-caliber technical and skilled professionals and nurturing foundational R&D capabilities. The depth, breadth, and effectiveness of their industry-education integration directly underpin the nation's digital talent reserves and core competitiveness in the digital economy. Distinct from vocational institutions that prioritize job-specific skill training and employment placement[3], industry-education integration in applied universities is characterized by greater complexity and forward-looking orientation: it requires not only alignment with current industrial job demands but also leadership in driving technological application innovation within regional industrial clusters, while simultaneously fostering students' practical operational competencies and their capacity for sustainable technological adaptation. However, traditional industry-education integration models—typically

structured as fixed, point-to-point cooperative agreements—have proven insufficient to address the exponential iteration of industrial technologies, the cross-disciplinary convergence of knowledge systems, and the upstream shift of innovation chains. Chronic challenges, including outdated curriculum systems, insufficient industry practice experience among faculty, misalignment between practical training and real-world industrial scenarios, and loosely governed collaborative mechanisms, have become increasingly salient. Notably, digital technology is not only reshaping industrial production modes and organizational forms but also fundamentally revolutionizing the production, dissemination, and acquisition of knowledge in the educational domain, necessitating systemic reforms to the organizational structure, teaching processes, evaluation systems, and governance capabilities of applied universities.

Against this backdrop, there is an urgent need to adopt an integrated, systematic theoretical perspective to conduct in-depth logical scrutiny, diagnose inherent practical bottlenecks, and reconstruct pathways for industry-education integration in applied universities in the digital era. The Technology-Organization-Environment (TOE) framework posits that an organization's adoption and deepening of innovative practices stem from the complex interaction and synergistic evolution of technological attributes, internal organizational structures, and external environmental contexts. Grounded in this analytical framework, this paper systematically explicates the intrinsic logic of industry-education integration in the digital age, diagnoses the root causes of its practical challenges, and ultimately constructs a context-adapted practical system for industry-education integration in applied universities amid digital transformation.

2. Logical Reconstruction of Industry-Education Integration in Applied Universities in the Digital Era

Based on TOE theoretical framework, initially proposed by Tornatzky and Fleischer in 1988 [4], this analytical approach was originally applied to research in the realm of enterprise technological innovation. Its enduring relevance stems from its capacity to capture the dynamic interplay among technological affordances, organizational capabilities, and environmental contingencies. In the context of applied universities, industry-education integration is undergoing a fundamental paradigm shift: no longer confined to transactional resource complementarity (e.g., internship placements), it is advancing toward strategic innovation symbiosis—characterized by co-defined curricula, co-developed technologies, co-governed platforms, and co-produced knowledge. This transition reflects the deepening convergence of education, industry, and digital infrastructure in the digital era [5]. The TOE framework thus provides a theoretically grounded, structurally coherent lens to reconstruct the logic of industry-education integration in applied universities—mapping how digital transformation reshapes its technological foundations, reconfigures its organizational architectures, and reorients its environmental engagements.

(1) Technological Dimension: From Enabling Tools to Integrated Digital Infrastructure

Digital technologies serve as the primary catalyst for systemic advancement in industry-education integration. Their permeating, adaptive, and restructuring properties drive continuous iteration across teaching, research, and practice—fundamentally reconfiguring the alignment between talent development pathways and industrial innovation cycles [6]. Historically, conventional teaching tools—including physical laboratories, training workshops, and analog simulation equipment—constituted essential infrastructural supports for skills-based instruction and foundational knowledge transmission. While still operationally relevant, these legacy assets increasingly face functional obsolescence amid rapid industrial digitization. In contrast, next-generation digital technologies—such as artificial intelligence, big data analytics, cloud-native platforms, the Industrial Internet of Things, and digital twin systems—have catalyzed the emergence of integrated digital infrastructure: intelligent pedagogical platforms, high-fidelity virtual simulation environments, and university-industry collaborative R&D data mid-platforms. These infrastructures transcend auxiliary functions; they constitute the operational backbone of digitally enabled integration. Centered on data as a strategic asset and orchestrated through interoperable digital systems, they underpin three core transformations: (i) the digitalization of teaching processes; (ii) the intelligentization of talent assessment; (iii) the integration of educational and industrial innovation workflows. Specifically, digital twin technology enables dynamic, physics-informed modeling of complex industrial scenarios—facilitating contextualized problem-based learning, enabling precise calibration of training sequences, and supporting multi-stakeholder co-innovation across academic and enterprise R&D teams. Its end-to-end deployment in university-industry collaboration directly mitigates the persistent “dual-isolation” phenomenon—where educational practices remain decoupled from industrial realities. Intelligent teaching platforms, in turn, transform raw

educational data into actionable insights for curriculum optimization and talent pathway forecasting. University-industry R&D mid-platforms shift collaborative innovation from sequential, siloed stages to agile, feedback-driven cycles. Virtual simulation training systems elevate practical pedagogy from experiential replication to precision competency scaffolding—aligning skill acquisition with evolving industrial capability requirements. Collectively, this technological evolution signifies a structural upgrade: from discrete, tool-level digitalization to systemic, infrastructure-level digital integration—thereby enabling scalable, sustainable, and innovation-oriented industry-education integration.

(2) Organizational Dimension: Synergistic Evolution of Multiple Stakeholders

The effectiveness of technology empowerment is highly contingent upon the acceptance and adaptability at the organizational level. Industry-education integration in application-oriented universities involves multiple stakeholders, including enterprises, government bodies, and research institutions. Its organizational logic centers on dismantling disciplinary and institutional barriers to unleash systemic efficacy. In the digital era, industry-education integration requires all parties to transcend simplistic resource exchanges or student internship arrangements and instead form an “innovation and talent development community” grounded in shared developmental responsibilities. Traditional bureaucratic management emphasizes vertical control and departmental insularity, with decision-making authority being relatively centralized. As industry-education integration continues to expand and deepen, the previously university-dominated management model has proven inadequate in addressing the complex and rapidly evolving demands of industries. Consequently, leveraging digital technologies to reshape traditional bureaucratic structures and foster a collaborative innovation governance mechanism has become imperative. In this context, the endogenous roles of enterprises, industry associations, research institutions, and other stakeholders are increasingly prominent, each contributing distinct governance functions to industry-education integration. Digital innovation serves as a critical driver in transitioning from bureaucratic control to networked collaboration. Universities, enterprises, governments, and industry associations emerge as key governance actors in digitally empowering industry-education integration, jointly unleashing its multifaceted effects while continuously enhancing their participatory efficacy. The diversification of stakeholders further renders the governance landscape of industry-education integration more open, orderly, and stable. By leveraging strategic synergy to provide governance advantages for industry-education linkages, the governance framework is restructured from a monocentric model to a core-led, multi-stakeholder approach. Mechanism innovation facilitates the shift from fragmented management to collaborative governance. Process reengineering enables the transition of R&D outcomes toward benefit-sharing development. From an organizational perspective, the empowering role of universities, enterprises, governments, industry associations, and other entities in technology implementation can be elucidated. This promotes interaction and interconnection among diverse stakeholders, establishing a “holistic, project-based, outcome-oriented” teaching-R&D quality assurance mechanism. By integrating real-world R&D projects as the core of capstone designs or curricula, learning

outcomes, R&D contributions, and competency certifications are unified, thereby advancing the transformation of digital technology–empowered industry-education integration from bureaucratic management to collaborative innovation networks.

(3) Environmental Dimension: Transcending Physical Boundaries Toward an Open and Integrated Ecosystem

Environmental adaptation serves as a critical driver for elevating the developmental landscape of industry-education integration. Within this context, institutional mechanisms and platform development are leveraged to construct digitally-enabled scenarios characterized by virtual-physical interaction and digital-real fusion, thereby fostering spatial complementarity and facilitating cross-domain flows between industry and education. Campus spaces function as fundamental carriers for talent development, and their spatial integration enables the free movement of educational and industrial resources. Traditionally, enclosed campuses have established relatively self-contained educational systems through physical boundaries and disciplinary silos, providing a stable environment for knowledge dissemination.

With the advent and innovation of digital technologies, dynamic collaboration mechanisms driven by both physical and virtual dimensions can effectively dismantle information silos and resource barriers in industry-education cooperation. The construction of a technology-enabled environment focuses on digital empowerment, employing big data analytics for institutional design and dynamic adjustment to establish a system. This framework aims to achieve internal synergy between human and intelligent environments, as well as external coupling between technological applications and their contexts, thereby expanding from physical and informational domains to an interactive, digitally-augmented space.

Policy coordination provides institutional safeguards for industry-education development, shifting demand response from passive reactivity to proactive adaptation. Platform development offers application scenarios that transition resource allocation from geographical constraints to coordinated complementarity. A quality culture fosters a governance ecosystem, promoting outcome evaluation from static presentation to dynamic evolution. Additionally, resolving historical industry-education dichotomies requires contextualized institutional and platform construction to create an integrated environment blending virtual and physical elements. From an environmental perspective, factors such as institutions and platforms amplify the efficacy of digital technologies, collectively building a robust external ecosystem that supports collaborative innovation and talent cultivation among universities, enterprises, governments, and society.

3. Analysis of Practical Challenges in Industry-Education Integration for Applied Universities in the Digital Era

Although the TOE framework clearly delineates a novel perspective on industry-education integration amid digital transformation, various structural challenges persist in the practical implementation within applied universities.

(1) Challenges in the Technological Dimension

There exists a "campus-enterprise" disjunction in the data flow between higher education institutions and industries,

which hampers the digital integration and innovative development of industry-education collaboration. Firstly, the circulation of data elements is hindered. Investigations into industry-education integration in applied universities reveal that data sharing faces horizontal connectivity issues, with academic administration, research management, and enterprise production systems operating in silos and lacking regular data interconnectivity. When leveraging technology to facilitate industry-education integration, the dispersion of data elements across various operational systems within universities, coupled with insufficient technical integration, results in data silos and barriers between academia and industry. Furthermore, inadequate data governance on collaborative platforms exacerbates the fragmentation and lack of cohesion in industry-education initiatives, leading to digital bottlenecks in the integration process (as discussed in "The Mechanism, Challenges, and Pathways of Industry-Education Integration in Vocational Education under Digital Transformation").

Secondly, a digital divide impedes technological innovation. Studies indicate that applied universities suffer from outdated digital R&D infrastructure, creating foundational gaps that constrain the level of digital research and development and hinder technological advancement. Due to unsustainable funding for digital technology investments and subsequent maintenance, the digital transformation of collaborative R&D in universities lags. Additionally, the superficial depth of coverage provided by university-enterprise collaboration platforms curtails the enabling effect of digital technologies in industry-education integration. The delayed real-time response capabilities of universities and the digital divide between academia and industry weaken the driving force of digital technology in enhancing talent development, further stifling innovation vitality and impeding deeper collaboration.

Thirdly, digital application capabilities are misaligned with societal needs. A gap in technological innovation literacy between university faculty and students and industry requirements leads to a skills mismatch. As digital transformation and iterative upgrades raise the threshold for technology usage, some educators lack proficiency in industry-grade digital tools and data analysis skills, while students lack practical experience in applying digital technologies within real-world projects. This obstructs the empowerment of digital technology in advancing industry-education integration. The existing disparity between university education and corporate training also results in deficiencies in students' digital literacy, with relatively underdeveloped industrial thinking that lags far behind the competencies of enterprise engineers in digital production and innovative application. Consequently, effective deepening of industry-education integration is challenging, resulting in a disconnection between supply and demand.

(2) Organizational Dimension Dilemma

At the organizational level, the deep-rooted "bureaucratization" governance inertia and "superficial" collaboration have created significant obstacles, highlighting the contradiction between the need for deep transformation and the actual progress of university-enterprise collaboration. This is manifested in three aspects. First, the "bureaucratization" inertia in the governance structure is hard to break, and the organizational barriers for cross-domain collaboration are severe. The rigid hierarchical system within universities, such as "university - college - department -

major", along with the bound disciplinary evaluation system, has formed a path dependency, making it difficult to adapt to cross-domain collaboration based on industrial demands. When forming project teams across colleges and disciplines to tackle real industrial problems, they often get stuck in a "connected but not integrated" situation due to disputes over resource allocation, ambiguous ownership of achievements, and conflicting evaluation standards, severely suppressing organizational vitality. Second, university-enterprise cooperation is locked in a "superficial" mode, making it difficult to establish strategic alliances. Currently, university-enterprise cooperation is still trapped in shallow transaction models such as "hanging internship base signs" and "teachers undertaking sporadic horizontal projects". The participation of enterprises is limited to the end stage of talent cultivation and short-term technical services, making it difficult to deeply integrate into core aspects such as curriculum design, teaching resource development, and long-term research planning. A deep binding mechanism of "jointly setting goals, jointly managing the process, jointly sharing achievements, and jointly bearing risks" has not yet been established between universities and enterprises, and collaboration remains at a "physical superposition" rather than a "chemical reaction". Third, the internal driving force for jointly established entities is insufficient. Due to the lack of a clear property rights definition, clear risk allocation, and long-term stable mutual trust framework, enterprises are hesitant about jointly establishing physical innovation platforms. They are not only worried about the leakage of key technical secrets during collaborative research and development but also concerned about the mismatch between the costs of equipment investment and personnel deployment in the early stage and the long-term return on talent cultivation. This "university enthusiasm but enterprise coldness" dilemma makes it difficult for universities and enterprises to form stable strategic alliances, and the construction of physical collaborative innovation platforms remains at the stage of intention agreements, failing to transform into substantive carriers supporting industry-education integration.

(3) Environmental Dimension Challenges

Although numerous policies have been introduced at the national level, implementation at local and institutional levels often encounters significant obstacles due to the absence of operable implementation guidelines, insufficient inter-departmental coordination, and a lack of accountability exemptions and error-tolerance mechanisms[7]. Consequently, policy effectiveness diminishes progressively across administrative tiers. Concurrently, there is a notable shortage of "dual-qualified" faculty equipped for industry-education integration in the digital era. Existing teaching staff exhibit deficiencies in industry practice capabilities and digital R&D competencies. Moreover, the faculty evaluation system predominantly relies on conventional academic metrics such as publications and grants, while contributions to industry-academia collaboration and technology transfer remain undervalued in promotion criteria, thereby severely dampening intrinsic motivation for deep engagement. At the societal level, intermediary service systems—including specialized technology manager teams bridging universities and industries, as well as regional industry data service centers—are underdeveloped, failing to effectively reduce transaction costs and risks associated with collaborative innovation.

The aforementioned challenges across technical,

organizational, and environmental dimensions converge most acutely in talent cultivation. Disciplinary silos persist widely, and curricula often lag behind industrial needs by 3–5 years, resulting in a severe mismatch between acquired knowledge and practical industry demands. Faculty generally lack hands-on experience in cutting-edge industrial R&D and the ability to translate engineering challenges into pedagogical resources, reflecting systemic weaknesses in industry-education integration capabilities. Industry mentors, constrained by institutional barriers, struggle to deeply engage in teaching systems and graduate project supervision, preventing substantive "dual-teacher" collaboration in education. Practical training platforms tend to be simulation-based, with a conspicuous absence of authentic environments tackling "real-world projects, real conditions, and real pressures" directly linked to corporate R&D units. To address these systemic challenges, comprehensive structural reforms are imperative.

4. Constructing a Practical Framework for Synergistically Overcoming the Triple Dilemma

Based on the diagnostic analysis utilizing the TOE framework, overcoming these challenges necessitates the establishment of a systematic practical framework that integrates technological empowerment, organizational restructuring, and environmental optimization, with a dedicated focus on the core mission of "innovative talent cultivation" in applied universities.

(1) Technological Breakthrough: Establishing an Intelligent Integrated Innovation Foundation to Overcome Barriers in Technological Empowerment

To address issues within the technological dimension—such as data silos, inadequate alignment of technical tools with the demands of industry-education integration, and inefficient flow of key elements—a unified digital infrastructure serves as the core support. This involves creating an intelligent, integrated innovation platform that spans teaching, research, and industrial applications, facilitating the transition of digital technologies from auxiliary tools to a deeply embedded digital foundation for industry-education integration. Implementation will proceed along two primary trajectories.[8]

From one perspective the establishment of unified data standards and open interfaces for all scenarios encompassing teaching, research, and management will dismantle technical barriers among internal university systems, corporate R&D management platforms, and regional industrial internet systems. Beyond basic teaching management functions, the platform will deeply integrate four core modules: intelligent matching of industrial technological needs, cross-organizational collaborative management of R&D projects, sharing of experimental data and simulation models, and end-to-end management of achievements commercialization and intellectual property. This integration enables precise alignment of university-enterprise resources, facilitates multi-stakeholder online collaboration, ensures efficient flow of data elements, and accelerates the transformation of innovative outcomes, thereby addressing critical pain points such as data fragmentation and insufficient collaborative innovation.

From another, the development of a digital twin-based practical training and innovation application system will be

pursued. In collaboration with leading regional enterprises and specialized "little giant" firms, digital modeling of key industrial processes, complex product prototypes, and typical R&D scenarios will be conducted to establish digital twin laboratories. Leveraging these laboratories, virtual simulation training and R&D innovation scenarios will be developed, enabling students and faculty to conduct low-cost, high-risk verification of principles, process optimization, and innovation experiments. This approach—"trial and error in virtual environments, innovation in real-world applications"—effectively reduces physical R&D costs, accelerates technological iteration, enhances the digital technology application and innovation capabilities of both instructors and students, and ensures that practical education is closely aligned with industrial development needs.

(2) **Organizational Restructuring: Refining the Synergistic Innovation Institutional Framework Based on "Governance as the Backbone, Mechanism as the Key"**

To address the aforementioned challenge of "rigid governance," it is essential to focus on innovating governance structures and establishing incentive-compatible mechanisms to develop a collaborative system that deeply integrates multiple stakeholders, thereby advancing industry-education integration from superficial cooperation to substantive convergence. First, establish a substantive "Innovative Talent Development Community." Promote joint capital injection by local governments, application-oriented universities, enterprises, and investment institutions, and implement a dean responsibility system under the leadership of a board of directors. Grant it independent authority in personnel recruitment, financial management, curriculum design, outcome disposition, and profit distribution, creating a "reform special zone" to break through the constraints of traditional bureaucratic systems, stimulate market entities' motivation to participate, and form a collaborative governance architecture with clear responsibilities and efficient operation. Second, innovate incentive mechanisms for deep collaboration. Develop a credit bank and innovation achievement substitution system where students participating in real enterprise R&D projects, achieving technological breakthroughs, or obtaining patent applications can directly exchange these for course credits or substitute graduation projects; teachers' technical services and income from achievement transfers can be proportionally converted into research workload or additional points for professional title evaluations. Implement dual appointments between enterprises and universities: when core technical talents from enterprises are appointed to universities, their teaching work is incorporated into enterprise performance evaluations; university faculty working deeply within enterprises as engineers have their industrial contributions directly linked to academic title promotions, fostering two-way mobility of personnel between industry and academia. Establish a "horse-racing mechanism" for assessing the effectiveness of industry-education integration. Utilize big data to monitor in real time indicators such as the number of collaborative projects, joint patents, graduate employment quality, and value of technical contracts across various majors and platforms. Link evaluation results with resource allocation for academic units, creating a healthy competitive environment that encourages benchmarking and mutual advancement.

(3) **Environmental Optimization: Constructing an Innovative Ecosystem and Resilience System for Industry-Education Integration**

Curriculum serves as the core vehicle for talent cultivation, whose structural design must resonate with the trajectory of regional industrial and technological advancement, fundamentally addressing the practical challenge of "curricular lag behind industrial development." Establishing a "Curriculum Development Center" jointly formed by academic faculty and industry experts is essential, positioning it as a central hub for dynamic curricular updates[9]. This center would rapidly deconstruct and modularly reorganize genuine technological challenges and engineering practice cases from enterprises, creating "micro-degree programs" and project-based course clusters to form an adaptive, dynamic curriculum system aligned with industrial evolution. Such a mechanism ensures timely iteration and upgrading of course content in sync with technological progress, facilitating precise alignment between instructional materials and industrial R&D needs, thereby enhancing the compatibility of industry-education integration.

Faculty are the "soul" of industry-education integration, as their academic proficiency and industrial practical experience directly determine the depth and effectiveness of collaborative talent development. Mandating a cumulative minimum of one year of full-time corporate R&D engagement for junior faculty prior to promotion to associate professor should be established as a rigid evaluation criterion, fostering a transition from "academic-focused" to "industry problem-solving" orientations among campus instructors. Concurrently, establishing "Industry Mentor Workstations" to systematically incorporate corporate technical experts into fixed collaborative teams with campus faculty will facilitate joint supervision of graduate designs and collaborative applications for R&D projects. This approach transcends traditional lecture-based superficial collaboration models, constructing a sustainable mechanism for bidirectional faculty mobility and symbiotic knowledge integration between academia and industry, thereby fortifying a stable talent support system for high-quality industry-education integration.

Practice constitutes the fundamental link for testing and enhancing professional competencies, requiring multi-tiered platform synergies to achieve progressive training from simulated exercises to real-world applications[10]. On campus, leveraging digital twin technology platforms to establish project-incubation training laboratories enables students to conduct end-to-end training from conceptual validation to physical prototyping in low-risk environments. Off campus, co-establishing and sharing "Engineering Centers" with industry leaders provides students with scalable platforms for process validation and performance testing. At the regional level, actively integrating into local enterprise cultivation systems promotes deep alignment between student graduation projects, faculty research initiatives, and actual demands of regional economic development, achieving closed-loop coupling between talent cultivation and industrial innovation contributions. This practice framework forms an organic dynamic cycle where curricular content, faculty expertise, and industrial technological advancement interact synergistically, ultimately forging an innovative ecosystem for industry-education integration with both adaptability and developmental resilience.

5. Conclusion and Future Outlook

As the core carriers of industry-education integration, application-oriented universities focus on cultivating high-

quality digital talents that are suitable for the digital transformation and innovative development of industries. Based on the TOE theoretical framework, this paper systematically reveals the three inherent evolution logics of industry-education integration in the digital age and accurately diagnoses the deep-seated constraints that are contrary to these evolution logics in current practice. In response to the above practical difficulties, this paper constructs a "five-dimensional integration" practical system, which closely aligns with the positioning of application-oriented universities and provides an operational theoretical reference and practical guideline for breaking through the bottlenecks of industry-education integration and promoting in-depth collaboration.

In the future, the high-quality development of industry-education integration in the digital age needs to be vigilant against the cognitive bias of "technology supremacy", adhere to the symbiotic evolution of technology, organization, and environment, continuously enhance the empowerment effect of digital technology, optimize the organizational collaboration mechanism of multiple subjects, and improve the environmental support system, to achieve a deep connection between the education chain, talent chain, and industrial chain, innovation chain, and continuously inject endogenous impetus into the high-quality development of industries and the integrated development of urban and rural areas.

Acknowledgments

The authors would like to acknowledge the financial support from the Guizhou Provincial Teaching Content and Curriculum System Reform Project (2023305), the "Golden Course" of Soil Science in Guizhou Province (20252030700), the "Golden Course" of Cartography in Guizhou Province (20230225), and the Curriculum Ideological and Political Education Reform Project of Liupanshui Normal University (LPSSYkcszjg202408029).

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