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Skill-Based Education Driving the Low-Altitude Economy to Empower Industrial Development: Mechanisms, Challenges, and Pathways

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The low-altitude economy, centered on civil manned and unmanned aerial vehicles, is profoundly reshaping industries such as logistics, agriculture, urban management, and emergency response. However, the rapid expansion of this sector has exposed a critical mismatch between the growing demand for skilled professionals and the insufficient supply of qualified talent. This paper examines how skill-based education can empower industrial development through the low-altitude economy, identifying three core mechanisms: knowledge transmission, technology translation, and job matching. It then analyzes major challenges including outdated competency standards, inadequate practical training resources, shortages of qualified instructors, shallow industry, education collaboration, and negative social perceptions that reduce career attractiveness. The study proposes systematic solutions: building a competency-based dynamic curriculum, establishing virtual-physical integrated simulation platforms, implementing a dual-track instructor development system, creating full-life-cycle industry, education partnerships, and improving multi-stakeholder governance. A discussion section further addresses the articulation between vocational and academic education, regional resource equity, cultivation of ethical and safety awareness, lifelong learning systems, and international perspectives. This research provides a theoretical framework and practical guidance for leveraging human capital to sustain the growth of the low-altitude economy.

Keywords: skill-based education, low-altitude economy, industrial empowerment, industry-education collaboration, talent development

Background

Characteristics and Growth of the Low-Altitude Economy

The low-altitude economy refers to an integrated economic form that uses civil manned and unmanned aircraft operating in low-altitude airspace, typically below 1,000 meters and extendable to 3,000 meters where needed, as its primary carriers, driving the convergence of manufacturing, operations, services, and support industries (Yang, 2026). In recent years, advances in battery energy density, autonomous navigation algorithms,

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communication link reliability, and lightweight materials have greatly expanded aircraft performance boundaries, leading to explosive growth in commercial applications (Zhou et al., 2025). In urban logistics, drone delivery has reduced last-mile transit times to minutes, easing terminal distribution bottlenecks. In agriculture, crop-dusting drones enable precise and large-scale spraying, significantly lowering manual labor risks (Zhou et al., 2025). In infrastructure inspection, drones equipped with multispectral cameras and LiDAR efficiently detect faults in power lines, oil pipelines, bridges, and tunnels. In public safety, firefighting drones and emergency communication relay drones have become essential rescue tools. Meanwhile, electric vertical takeoff and landing aircraft are undergoing certification and demonstration trials in multiple cities worldwide under the concept of urban air mobility (Lin et al., 2025; Xiao & Li, 2024).

Industry forecasts estimate that the global low-altitude economy market will exceed one trillion U.S. dollars within the next decade. Its value chain spans upstream research and manufacturing of aircraft, midstream operation services and air traffic management, and downstream application development and ancillary services (Luu et al., 2026). This industry is uniquely characterized by extremely short technology refresh cycles, with consumer-grade drones averaging less than 18 months between generations; highly fragmented application scenarios where the same aircraft model must be adapted to different payloads and workflows across sectors; stringent safety and regulatory requirements covering airspace management, privacy protection, and noise control; and strongly interdisciplinary skill demands. Practitioners must simultaneously master flight control, equipment maintenance, data analysis, regulatory compliance, and emergency response. These features make the low-altitude economy a typical technology-intensive and scenario-driven industry whose large-scale development depends on an ample supply of highly competent skilled workers (Wei, 2026).

The Functional Role and Enabling Logic of Skill-Based Education

Skill-based education aims to cultivate technical application abilities, hands-on operational competencies, and career transferable skills, distinguishing it from theory-oriented academic higher education. Within modern industrial systems, skill-based education serves as an intermediary that transforms frontier technological achievements into actionable work procedures, translates vague industry needs into concrete curricular standards, and molds individual workers into qualified professionals meeting specific job specifications. From a human capital perspective, skill-based education reduces search and matching costs in labor markets, accelerates the diffusion of innovations from laboratories to production floors, and thereby enhances overall system efficiency (Lan & Chen, 2026).

In the context of the low-altitude economy, the enabling logic of skill-based education operates through three mechanisms.

First, the knowledge transmission mechanism. The low-altitude economy draws on cross-disciplinary knowledge spanning aerodynamics, automatic control, satellite navigation, wireless communications, and image recognition. Skill-based education reorganizes and simplifies this knowledge according to job requirements, forming easily understandable training content that enables individuals without deep science or engineering backgrounds to quickly acquire necessary theoretical foundations (Zheng, Zhou, & Du, 2025).

Second, the technology translation mechanism. Every hardware or software upgrade in aircraft requires corresponding updates in operation and maintenance skills. By maintaining close ties with equipment manufacturers, skill-based education incorporates the latest product specifications, operating manuals, and troubleshooting guides into teaching, ensuring trainees stay current with mainstream devices and shortening the time window between new technology release and widespread field adoption (Wang & Chen, 2025).

Third, the job matching mechanism. Different subsectors of low-altitude operations present distinct requirements. Agricultural spraying emphasizes uniform coverage and route planning, power line inspection focuses on defect identification accuracy and data management, while logistics delivery prioritizes landing site selection and obstacle avoidance strategies. Skill-based education offers specialized tracks and contextualized training projects that help learners build scenario-specific capabilities, enabling precise conversion from general skills to occupation-specific ones (Guo, 2025).

Currently, the low-altitude economy is transitioning from a technology validation phase to a phase of large-scale commercial deployment. Whether this transition succeeds hinges largely on whether there exists a sufficient number of well-trained skilled workers with appropriate composition and quality. Yet the reality is concerning. On the demand side, positions for pilots, maintenance technicians, operators, data analysts, and air traffic coordinators are growing exponentially. On the supply side, the scale, quality, and pace of training all lag behind. Many small and medium-sized enterprises report difficulties finding qualified pilots, inability to use purchased equipment, and rapid obsolescence of employee skills after initial training. This supply-demand imbalance has become a core bottleneck restricting the low-altitude economy's ability to empower broader industrial development.

Challenges

Outdated Competency Standards Relative to Industry Evolution

The technological trajectories and application models of the low-altitude economy continue to evolve rapidly, while competency standards and occupational certifications in education often exhibit significant delays. For example, swarm control technology is now widely used in logistics delivery, light shows, and coordinated surveillance, yet most training programs still focus on single-unit manual piloting, lacking systematic instruction in swarm mission planning, multi-agent collision avoidance, and distributed data processing. Similarly, because airworthiness certification standards for electric vertical takeoff and landing aircraft are not fully finalized, training for their maintenance personnel lacks authoritative reference frameworks. Institutions develop their own curricula in isolation, resulting in credentials that are not mutually recognized across regions or companies. Such standard lags waste educational resources and impede orderly labor mobility.

Severe Shortage of Practical Training Resources

Skill development in the low-altitude economy heavily depends on hands-on practice, but access to expensive aircraft, legal flying airspace, and professional simulators is extremely limited. An industrial-grade drone may cost tens of thousands of U.S. dollars, and a complete set of ground maintenance equipment for electric vertical takeoff and landing aircraft is even more costly. Most vocational schools cannot afford enough teaching units. Meanwhile, obtaining permits for legal flight operations involves complex procedures and restricted time slots, giving students very few opportunities for actual flying. More critically, real-world complexities such as GPS signal blockage in urban canyons, electromagnetic interference near high-voltage lines, turbulence effects over mountainous terrain, and emergency mechanical failures are nearly impossible to replicate on campus. As a result, many graduates who pass theoretical exams and basic operation tests become helpless when confronted with non-standard situations in the field.

Structural Shortage of Qualified Instructors

The low-altitude economy is a quintessential emerging interdisciplinary field requiring instructors to possess knowledge and experience spanning aeronautical engineering, electronics, computer science, operations research, and safety management. Currently, most teachers come from two groups. One group consists of those who transferred from traditional disciplines such as mechanical engineering, automation, or surveying. They have solid theoretical foundations but lack frontline industrial experience and sensitivity to the latest trends. The other group comprises a small number of retired pilots or corporate engineers who are rich in practical expertise but relatively weak in pedagogical methods and curriculum development. Moreover, because compensation in the education sector is significantly lower than in industry, talented corporate technicians have little incentive to join teaching faculties. This shortage directly degrades instructional quality, creating a vicious cycle where poorly trained teachers produce inadequately prepared graduates.

Shallow Industry-Education Collaboration

Although school-enterprise cooperation and industry-education integration are widely advocated, actual implementation often remains superficial. Companies hesitate to open their core business scenarios and data due to concerns about trade secrets, liability for accidents, and disruptions to production schedules. Schools, constrained by fixed syllabi, rigid class hours, and traditional assessment methods, struggle to flexibly respond to employers’ immediate hiring needs or seasonal workload fluctuations. Differences in objectives, management styles, and timelines lead collaborative efforts to stagnate at symbolic levels such as signing agreements, hosting brief visits, or arranging occasional lectures. Furthermore, the fragmentation of occupational certification systems, with licenses issued by aviation authorities, certificates granted by industry associations, and training credentials provided by manufacturers, lacks mutual equivalence, adding institutional friction to labor mobility.

Negative Social Perceptions and Weak Talent Attraction

For a long time, society has held biased views toward skill-based occupations, often equating them with manual labor or low-status jobs. This stereotype discourages talented youth from pursuing careers in the low-altitude economy. Additionally, some positions such as drone pilots involve harsh working conditions, including outdoor operations, frequent travel, and exposure to adverse weather, along with unclear career advancement paths, leading to high turnover rates. Improving the social prestige of skilled roles, enhancing career expectations, and constructing predictable growth ladders are soft challenges that skill-based education must address alongside technical issues.

Methods

Building a Competency-Based Dynamic Curriculum

Replace the traditional discipline-centered curriculum structure with a modular design organized around job competencies. Specifically, industry associations can lead periodic job capability mapping exercises involving leading enterprises and educational experts, identifying a three-tier architecture: general foundational competencies, specialized technical competencies, and scenario adaptation competencies. General foundational competencies include aviation regulations, meteorology basics, radio communication protocols, and fundamental flight principles. Specialized technical competencies cover operation and maintenance of different aircraft types, including multirotor, fixed-wing, helicopter, and electric vertical takeoff and landing, along with sensor and payload usage, data processing, and analysis. Scenario adaptation competencies feature customized modules for agriculture, logistics, inspection, security, and other subsectors. Course content should be updated every six months to incorporate new equipment manuals, revised regulations, and emerging business models. Introduce a micro-credential system allowing learners to select and complete specific skill modules based on their background and career plans, enabling flexible just-in-time learning.

Establishing Virtual-Physical Integrated Simulation Platforms

Leverage digital twin, virtual reality, augmented reality, and mixed reality technologies to construct a comprehensive low-altitude economy simulation training system. Core modules should include: high-precision meteorological environment simulation capable of generating wind fields, precipitation, fog, and thunderstorms; three-dimensional urban geographic information modeling incorporating buildings, utility poles, trees, and moving vehicles; multi-type flight performance simulation accurately replicating aerodynamic characteristics and power responses of different aircraft; and a fault injection engine that randomly or prescribes failures such as engine shutdown, communication loss, GPS dropout, and control surface jamming. Trainees can repeatedly practice high-risk maneuvers in a safe virtual space, accumulating muscle memory and emergency response experience without fear of equipment damage or accidents. On top of this, leverage fifth-generation mobile networks and edge computing to enable remote operation of real drones located at suburban bases, effectively overcoming urban airspace scarcity. Build a training data asset repository and use behavior analytics to generate personalized skill profiles for each learner, precisely identifying weaknesses and recommending targeted exercises.

Implementing a Dual-Track Instructor Development System

Create special industry professor positions to recruit experienced technical specialists from leading enterprises and research institutes as part-time faculty responsible for delivering specialized courses, guiding training projects, and sharing case studies. Simultaneously implement a teacher internship program requiring no less than 20 percent of full-time instructors each year to spend at least one month embedded in partner companies, participating in product testing, field operations, and customer training. Establish a teacher skill certification system that includes enterprise practice outcomes such as technical improvement suggestions, patents, and draft standards, along with competition coaching achievements and horizontal project funding, as core criteria for promotion, moving away from a sole reliance on publications and degrees. Encourage the formation of cross-institutional and cross-regional teaching communities using online collaboration platforms to share high-quality lesson plans, instructional videos, and test banks, and hold regular seminars to disseminate effective pedagogical practices.

Creating Full-Life-Cycle Industry-Education Partnerships

Build closed-loop mechanisms involving enterprises throughout the entire process from recruitment and training to internships and employment. At the recruitment stage, jointly develop targeted training agreements with clear employment intentions and salary expectations to attract high-quality candidates. During the training period, adopt a work-study alternation model where students spend one month studying theory on campus followed by two weeks rotating through company positions, bringing real problems back to the classroom for discussion, and repeating this cycle. For internships, implement a dual-mentor system: school teachers oversee theoretical guidance and thesis supervision, while company mentors handle hands-on coaching and safety oversight. Promote the establishment of regional low-altitude economy skilled talent alliances to unify competency certification standards, achieving one-time certification valid across multiple jurisdictions. Explore the creation of skill worker credit files recording individual training history, work performance, safety records, and continuing education activities, reducing employer screening costs while motivating practitioners to continuously improve.

Improving Multi-Stakeholder Governance

Skill-based education for the low-altitude economy involves governments, industry organizations, educational institutions, enterprises, and third-party evaluators. An efficient collaborative governance mechanism is needed. Recommend forming a committee composed of representatives from all stakeholders to formulate medium- and long-term development plans, coordinate resource allocation, and monitor educational quality. Introduce independent third-party evaluation agencies to periodically audit the effectiveness of training programs and certification schemes, publishing results to foster market-based competition that rewards quality. Establish a wage guidance index publication system to help enterprises set reasonable compensation levels for skilled positions, thereby enhancing career attractiveness.

Discussion

Articulation Between Vocational and Academic Education

The low-altitude economy requires both large numbers of frontline operators and maintainers as well as research and development personnel engaged in system design, algorithm development, and airspace planning. The former are primarily trained by vocational schools and training centers, while the latter come from bachelor's and graduate-level academic programs. These two streams should not be separated or opposed but rather form organic articulation pathways. For instance, dual-track routes combining skills and academic degrees could allow vocational graduates after several years of work experience to apply for applied bachelor’s or professional master's programs, while university students could take skill-oriented elective courses and earn corresponding certificates to enhance employability. The key lies in establishing credit transfer frameworks and qualification reference systems that make transitions smooth and transparent.

Regional Equity in Resource Distribution

Development levels of the low-altitude economy and the distribution of skill education resources vary considerably across regions. Economically advanced areas tend to host more aircraft manufacturers, better flying airspace, and more advanced training equipment, while less developed regions face triple deficits: no equipment, no venues, and no instructors. Without intervention, this disparity may widen industrial gaps. One possible approach is to promote enclave-style cooperative schooling, where high-quality institutions from prosperous areas establish branch campuses or training bases in underserved regions, taking advantage of lower land and labor costs. Another is to deliver premium course content to remote locations via distance education technology. Additionally, regional skilled talent dispatch centers could flexibly allocate workers according to fluctuating demand peaks and troughs across areas.

Cultivation of Ethical Awareness and Safety Culture

Rapid growth of the low-altitude economy brings numerous ethical and safety concerns: drone invasion of privacy, mid-air collisions, malicious hijacking, and noise nuisance. Skill-based education must go beyond technical proficiency and embed safety culture, legal awareness, and professional ethics as core competencies. A compulsory module on low-altitude safety and ethics should be added, covering airspace management rules, privacy protection principles, emergency response protocols, and reporting obligations. Furthermore, introduce safety behavior observation and correction mechanisms during training to instill a habit of thinking before acting and prioritizing safety. Only when safety consciousness becomes instinctive can the risks inherent in low-altitude operations be fundamentally reduced.

Building Lifelong Learning Systems

Given the rapid pace of technological change in the low-altitude economy, any one-time vocational education cannot meet practitioners' needs throughout their careers. Therefore, a lifelong learning system targeting incumbent workers must be constructed. Specific measures include developing an online micro-course platform offering bite-sized, anytime-accessible knowledge updates; establishing skill upgrading subsidy funds to encourage periodic return-to-school training; and introducing a skill passport system that records individuals' continuous learning trajectories and skill appreciation, serving as a basis for promotion and salary adjustment. A robust lifelong learning system not only sustains workers' employability but also ensures the long-term innovative vitality of the low-altitude economy.

International Perspectives

The low-altitude economy is a globally emerging industry where nations compete and cooperate on airworthiness standards, operational rules, and technological roadmaps. Skill-based education should appropriately incorporate internationally recognized occupational standards, such as those from the International Civil Aviation Organization and relevant aviation safety agencies, to cultivate talent with global vision and cross-cultural communication skills. At the same time, actively promote exchanges and visits with foreign counterparts, drawing on mature experiences in drone pilot training and electric vertical takeoff and landing aircraft maintenance certification in other countries, thereby elevating the international competitiveness of domestic skill development programs.

Conclusion

Skill-based education serves as a critical bridge that transforms the technological advantages of the low-altitude economy into industrial strength and moves the sector from pilot demonstrations toward large-scale commercial deployment. This paper systematically elucidates the internal logic through which skill-based education empowers industrial development via three mechanisms: knowledge transmission, technology translation, and job matching. It thoroughly analyzes five structural challenges: outdated competency standards, severe shortages of practical training resources, insufficient qualified instructors, shallow industry-education collaboration, and negative social perceptions. Correspondingly, it proposes systematic solutions across five dimensions: curriculum reconstruction, simulation platform upgrades, instructor workforce development, industry-education ecosystem optimization, and governance improvement. The discussion further explores deeper issues including articulation between vocational and academic education, regional equity, ethical and safety cultivation, lifelong learning systems, and international perspectives.

Looking ahead, as the application scenarios of the low-altitude economy continue to expand and technological boundaries keep shifting, the scope and nature of skill-based education must evolve dynamically. Only by positioning talent development within the broader context of industrial chains, innovation chains, and value chains, and by establishing rapid-response mechanisms and flexible adjustment capabilities, can the immense potential of the low-altitude economy to empower industrial transformation and upgrading be truly unleashed. Skill-based education is not merely a booster for industrial growth. It should also serve as a ballast stone ensuring the healthy, orderly, and sustainable operation of the low-altitude economy. When every practitioner possesses refined skills, rigorous attitudes, ingrained safety awareness, and a commitment to continuous learning, the grand vision of the low-altitude economy can take root and flourish, injecting sustained momentum into economic and social development.

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