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Exploration of AI-Empowered Talent Cultivation Pathways for Emerging Engineering Education in Integrated Circuits

Binrui Xu*, Jingyan Wu, Min Liu, Jincan Zhang, Yuxiang Li, Bo Liu

School of Information Engineering, Henan University of Science and Technology, Luoyang 471000, P. R. China
* **Corresponding author**: Binrui Xu (Email: 9906065@haust.edu.cn)

Abstract: Amid the profound convergence of artificial intelligence (AI) and integrated circuits (IC), traditional talent development models remain shackled by entrenched disciplinary silos, constrained practical training, and institutional decoupling between academia and industry. Grounded in the strategic paradigm of Emerging Engineering Education, this study transcends conventional tool-oriented perspectives by elevating AI to a transformative meta-capability that reshapes the entire educational ecosystem, thereby systematically exploring innovative pathways for AI-empowered IC talent cultivation. In response to evolving industrial imperatives for a conical interdisciplinary knowledge architecture and holistic systems engineering thinking, this research formulates a tripartite cultivation objective integrating knowledge, capability, and literacy alongside four overarching guiding principles. Anchored in this top-level blueprint, a comprehensive four-dimensional implementation framework is architected across curricular, pedagogical, faculty, and institutional dimensions. Specifically, this framework reconstructs a three-tiered progressive modular curriculum matrix spanning foundational, core, and frontier levels while forging a smart pedagogical paradigm that unifies personalized instruction, high-immersion virtual practice, and intelligent evaluation. Concurrently, it builds an interdisciplinary dual-qualified faculty force through synergistic external recruitment and internal training, and fosters a deeply collaborative industry-education community of shared future leveraging an intelligent crowdsourcing R&D platform and joint laboratories, ultimately delivering a systematic and actionable roadmap to overcome the critical talent bottleneck in the semiconductor sector.

Keywords: Artificial Intelligence, Curriculum Reconstruction, Emerging Engineering Education, Industry-education Integration, Integrated Circuits, Talent Cultivation.

1. Introduction

Driven by the burgeoning wave of next-generation information technology, artificial intelligence (AI) and integrated circuits (IC) have forged a symbiotic paradigm characterized by the bidirectional coupling of intelligence and computing power, profoundly reshaping the global semiconductor value chain. Against this transformative backdrop, the challenges confronting China's IC industry have escalated from isolated technological hurdles into a strategic predicament marked by dual deficits in both innovation and human capital, rendering the shortage of versatile talents capable of navigating the convergence of AI and IC particularly acute. Nevertheless, prevailing talent cultivation models remain severely misaligned with industrial imperatives, shackled by entrenched disciplinary silos, industry-education decoupling, and persistent bottlenecks in practical engineering training. Concurrently, responses from both academia and the educational sector have proven inadequate, as existing scholarship predominantly prioritizes technical implementation at the expense of pedagogical laws, while educational practices often settle for the superficial adoption of AI tools without catalyzing a fundamental paradigm shift in talent development. This pronounced structural contradiction, wherein educational evolution lags behind rapid industrial iteration, has emerged as a core bottleneck constraining the technological self-reliance and sovereignty of the national chip industry. Anchored in the visionary framework of Emerging Engineering Education, this study systematically explores an innovative pathway for AI-empowered IC talent cultivation, aiming to deliver a strategic solution that resolves the industrial talent impasse and elevates national core competitiveness.

2. AI Demands on IC Talent under Emerging Engineering

2.1. The Perspective of Emerging Engineering Education

Centered on cross-boundary integration and industry-education synergy, the advancement of Emerging Engineering Education provides an overarching guiding framework to resolve the structural imbalance in talent supply within the IC sector. This strategic perspective emphasizes that talent cultivation must be firmly anchored in national strategic imperatives and the evolving paradigm of deep industrial convergence between AI and IC, thereby thoroughly dismantling the entrenched disciplinary barriers separating pure chip design from pure AI algorithms. Consequently, the underlying logic of IC talent development must be fundamentally reconstructed around core competencies, propelling a profound transition toward an educational model oriented around both interdisciplinary convergence and authentic engineering practice. Such a paradigm shift necessitates not only consolidating foundational domain expertise in chip architecture and electronic design automation (EDA) tools, but also reinforcing the end-to-end penetration and seamless application of AI technologies across the entire IC development lifecycle [1].

2.2. Reshaping the IC Talent Competency Model

Driven by the core tenets of dismantling barriers, strengthening synergy, prioritizing competencies, and catalyzing iteration, Emerging Engineering Education seeks to systematically reconstruct the talent cultivation paradigm in response to the industrial reality of deep AI and IC convergence. Within this landscape, artificial intelligence is profoundly reshaping the foundational competency model of semiconductor professionals, propelling a transition from traditional single-skill frameworks toward a multi-pillar paradigm anchored in interdisciplinary convergence, engineering innovation, systematic thinking, and lifelong learning. This structural evolution manifests as a four-dimensional paradigm shift across knowledge, practice, cognition, and professional development [2].

In terms of knowledge architecture, talent must evolve from a traditional T-shaped profile to a conical structure that not only consolidates the core IC disciplinary foundation, but also deeply integrates AI methodologies to grasp the intrinsic interplay between algorithms and physical chip implementation, thereby supporting high-end innovations such as domain-specific architectures and AI-empowered EDA workflows [3]. Regarding engineering practice, the training mode must transition from resource-dependent physical verification to virtual simulation-driven generative creation, empowering students to leverage intelligent tools in resolving complex real-world challenges like performance optimization and fault diagnosis [4].

At the level of cognitive capability, learners need to transcend isolated module design to cultivate a holistic, full-stack systems perspective spanning algorithms, silicon, software, and applications, while seamlessly adapting to intelligent collaborative R&D paradigms. Finally, within the trajectory of professional growth, static knowledge acquisition must be upgraded to dynamic, adaptive learning capabilities, enabling future engineers to utilize AI instruments to track technological frontiers and achieve synchronous iteration of both theoretical knowledge and engineering expertise.

3. Objectives and Guiding Principles for IC Talent Cultivation

Building upon the preceding insights into the evolving competency model for IC professionals within the Emerging Engineering framework, this study endeavors to architect a talent cultivation pathway that systematically addresses industrial imperatives. Formulating such a transformative pathway necessitates a rigorous top-level blueprint, which begins by clearly delineating both its overarching cultivation objectives and core guiding principles.

3.1. Tripartite Talent Cultivation Objectives

To navigate the profound industrial transformation catalyzed by the deep convergence of AI and integrated circuits, this study establishes a tripartite talent cultivation objective integrating knowledge, capability, and literacy, systematically nurturing versatile, practice-oriented, and innovative Emerging Engineering professionals. Within the knowledge dimension, this framework takes core disciplinary expertise in IC design, fabrication, and EDA as its foundational bedrock while upward-integrating frontier AI technologies such as machine learning to construct a conical interdisciplinary knowledge architecture. Across the capability dimension, the objective focuses on forging four pivotal competencies encompassing cross-boundary integration, engineering innovation, system synthesis, and lifelong learning, thereby elevating students' practical proficiency in harnessing AI methodologies to resolve complex engineering challenges throughout the entire chip development lifecycle. At the literacy level, rigorous engineering ethics, a proactive innovative spirit, and a steadfast commitment to national technological self-reliance are internalized as the defining professional ethos of future engineers [5]. Operating in mutually reinforcing synergy, these three dimensions seamlessly bridge the developmental continuum from knowledge foundation and capability forging to literacy sublimation, ultimately cultivating a closed-loop and progressive educational ecosystem.

3.2. Formulating Scientific and Effective Guiding Principles

To guarantee the scientific rigor, technological advancement, and industrial adaptability of the cultivation pathway, this study formulates four progressively structured core guiding principles. Foremost among these is an orientation toward competency and literacy, which takes interdisciplinary innovative capability as the primary benchmark and propels a fundamental pedagogical transition toward capability forging and the cultivation of an engineering ethos. Building upon this foundation, the principle of deep cross-boundary integration endogenously embeds the technical logic of AI into the IC curriculum system to construct a composite interdisciplinary knowledge framework. Extending from curricular design to practical execution, collaborative industry-education co-construction leverages authentic enterprise projects and high-fidelity simulation platforms to forge a practice-oriented educational ecosystem characterized by industry-posed challenges and joint problem-solving. Furthermore, dynamic and forward-looking iteration establishes an agile response mechanism that continuously renews instructional content while nurturing students' lifelong learning capabilities. Spanning the entire continuum of educational philosophy, curricular content, practical training, and evolutionary mechanisms, these four overarching principles operate in tandem to construct a logically self-consistent and closed-loop talent development ecosystem.

In synthesis, the principle of competency and literacy orientation anchors the fundamental direction regarding what kind of talent to cultivate, while deep cross-boundary integration reconstructs the substantive curricular architecture of what to teach. Simultaneously, collaborative industry-education co-construction resolves the operational dilemmas concerning how to instruct and where to practice, whereas dynamic and forward-looking iteration furnishes an enduring institutional mechanism for the continuous evolution of the pedagogical system. Progressing in a tiered yet mutually reinforcing manner, these four overarching principles collectively forge a logically self-consistent and industry-integrated closed-loop ecosystem for Emerging Engineering Education, thereby laying a solid foundation for the subsequent implementation of the cultivation pathway.

4. AI-Empowered Implementation Pathways

4.1. Curriculum System Reconstruction

To dismantle entrenched disciplinary silos and overcome curricular obsolescence, it is imperative to construct a three-tiered progressive modular curriculum matrix spanning foundational, core, and frontier levels under the guidance of a dynamic AI-and-IC knowledge graph. At the foundational tier, introductory courses such as Introduction to Integrated Circuits and Fundamentals of Artificial Intelligence are established to consolidate both domain literacy and the algorithmic bedrock. Moving upward, the core tier deeply embeds AI-driven design methodologies and intelligent fault diagnosis modules into Chip Architecture Design and EDA Technology and Applications, thereby catalyzing bidirectional cross-disciplinary empowerment. Ascending to the frontier tier, advanced coursework exemplified by Intelligent Chip Design targets disruptive paradigms including Chiplet heterogeneous integration and compute-in-memory architectures to broaden students' horizons for cutting-edge innovation [6]. Concurrently, large language models and generative AI are leveraged to dynamically iterate the interdisciplinary knowledge graph and develop high-precision interactive instructional resources [7]. On this basis, authentic problem-oriented interdisciplinary project-based learning, typified by intelligent low-power chip design competitions, is comprehensively implemented to systematically hone students' innovative capabilities in resolving complex engineering challenges through end-to-end practical training.

4.2. Pedagogical Paradigm Transition and Practical System Optimization

Addressing the persistent bottlenecks of homogenized one-size-fits-all instruction and the prohibitive costs and high risks inherent in IC practical training, it is essential to construct a new smart pedagogical paradigm characterized by precision, immersion, and efficiency that integrates personalized instruction, high-immersion practice, and intelligent evaluation into a tripartite framework. At the instructional level, learning analytics big data and machine learning algorithms are leveraged to construct comprehensive student digital profiles, thereby customizing adaptive learning pathways and automated resource delivery to achieve precise individualized education. Within the practical dimension, a high-fidelity virtual platform integrating AI-assisted design, intelligent diagnostics, and full-flow simulation is established to cultivate a tape-out-free immersive environment permissive of unlimited trial-and-error iterations, effectively eliminating reliance on costly hardware and physical silicon fabrication. Across the evaluation phase, full-process multimodal learning data are captured and analyzed via specialized models to intelligently assess project outcomes, establishing a human-AI collaborative multidimensional evaluation loop that combines preliminary machine assessment with final faculty review. Interlocking seamlessly with one another, these three pillars collectively propel a fundamental paradigm shift from traditional unidirectional knowledge transmission toward a full-process AI-empowered pedagogical ecosystem.

4.3. Interdisciplinary and Dual-Qualified Faculty Development

Confronted with the structural shortcomings of monodisciplinary backgrounds and insufficient engineering experience among faculty members, it is imperative to implement a combined strategy of internal training, external recruitment, and application-driven development to forge a high-caliber dual-qualified and interdisciplinary teaching force. Through a synergistic approach to talent acquisition and cultivation, institutions should actively recruit high-level professionals with interdisciplinary AI expertise while systematically seconding in-house faculty to semiconductor enterprises for industrial fellowships, thereby reinforcing both cross-disciplinary instruction and hands-on engineering capabilities. Concurrently, dismantling departmental boundaries enables the formation of cross-boundary teaching and research teams anchored in modular course clusters and joint research projects, bringing together IC faculty, AI scholars, and enterprise engineers to collaboratively spearhead curriculum development and practical mentoring. Furthermore, a robust empowerment support ecosystem must be established by co-constructing intelligent lesson-preparation and simulation repositories, instituting dedicated pedagogical reform funds, and conducting regularized smart-teaching training programs, which collectively elevate faculty digital-intelligent literacy and innovative vitality to solidify the instructional cornerstone for AI-and-IC talent cultivation [8].

4.4. Industry-Education Integration Mechanism Innovation

To eradicate the chronic maladies of institutional decoupling between universities and enterprises as well as superficial collaboration, AI must be leveraged to reshape synergistic mechanisms and forge an industry-education community of shared future anchored in value co-creation, benefit sharing, and risk co-bearing. Regarding the collaborative modality, an intelligent crowdsourcing collaborative R&D platform is established to deconstruct authentic corporate engineering challenges into modular tasks, empowering students to collaboratively tackle technical bottlenecks with the support of AI-assisted tools and built-in intelligent tutors while enterprise engineers exercise remote quality control, thereby achieving bidirectional empowerment between high-level practical training and corporate R&D [9]. In terms of institutional carriers, the construction of AI-and-IC university-enterprise joint laboratories is deepened by comprehensively introducing cutting-edge EDA tools and industrial-grade process standards to jointly advance key technological breakthroughs, co-develop practical curricula, and front-load engineering protocols into the academic stage. At the level of governance and quality assurance, a multi-stakeholder collaborative mechanism encompassing universities, enterprises, and industry associations is refined through full-chain data analytics that dynamically diagnose corporate engagement depth and student job competency, ultimately forming a multi-dimensional governance closed loop of evaluation, feedback, and optimization that propels industry-education integration toward substantive and mutually beneficial synergy.

5. Conclusion and Future Prospects

Driven by the dual imperatives of Emerging Engineering construction and the national semiconductor strategy, this study addresses the pedagogical dilemmas arising from the deep convergence of artificial intelligence (AI) and integrated circuits (IC) by establishing a tripartite cultivation objective integrating knowledge, capability, and literacy alongside four overarching guiding principles. Anchored in this top-level design, a systematic four-dimensional implementation framework encompassing curriculum system reconstruction, pedagogical paradigm transition, faculty team forging, and industry-education mechanism innovation is architected to effectively dismantle entrenched bottlenecks including disciplinary silos, practical decoupling, and curricular obsolescence. Crucially, this research transcends the reductive limitation of viewing AI merely as an auxiliary instrument and elevates it to a transformative meta-capability that reshapes the entire educational ecosystem, which not only deepens the theoretical paradigm of interdisciplinary talent development in Emerging Engineering, but also delivers a panoramic and actionable roadmap for overcoming the critical chip talent bottleneck. Looking ahead, it is imperative to mobilize government, industry, academia, and research stakeholders to co-construct an AI-and-IC educational innovation consortium, leveraging institutional remodeling, resource aggregation, and synergistic iteration to translate these pedagogical explorations into a perennial fountainhead of high-caliber talent that underpins high-level technological self-reliance in the national IC industry and secures the commanding heights of global technological competition.

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