Education Reform and Development, 2025, Volume 7, Issue 12
https://ojs.bbwpublisher.com/index.php/ERD
Online ISSN: 2652-5372
Print ISSN: 2652-5364

Emerging Engineering Education Method Based on "Elements Aggregation" for Integrated Circuit Talent Cultivation

Yongqian Du, Nan Chen, Guifang Li, Shibin Liu

The School of Electronics and Information, Northwestern Polytechnical University, Xi'an, China

Abstract: Taking "Analog Integrated Circuit Analysis and Design", the key course of the integrated circuit major, as an example, this paper proposes a new engineering course teaching method based on "elements aggregation" for the cultivation of high-level integrated circuit engineering talents. The aim of this method is to realize the organic integration of the three-dimensional space of knowledge, ability and competence, and the organic integration of basic theory, scientific discovery ability and engineering application ability. The proposed teaching method ensures a multidimensional and composite high-quality engineering talent cultivation in integrated circuits in higher education institutions.

Keywords: Elements aggregation; Emerging engineering education; Engineering talent cultivation; Integrated circuit

Online publication: December 31, 2025

1. Introduction

The integrated circuit (IC) industry is a strategic, foundational, and pioneering sector in national economic and social development. It serves as the core and foundation for cultivating emerging strategic industries and promoting the deep integration of informatization and industrialization. However, there remains a significant gap in the cultivation of IC professionals, and the rapid development of the industry has placed new, higher, and more comprehensive demands on talent training [1,2]. As the most critical training ground for IC professionals, higher education institutions must engage in serious reflection: "Does the current teaching model meet the urgent demand for IC talent in China?" and "Can the current teaching model cultivate high-quality IC professionals capable of facing future challenges?"

The field of integrated circuits is characterized by several distinct features: on one hand, it is highly practical, requiring close integration of theory and practice; on the other hand, it involves complex and extensive specialized knowledge, with engineering practice emphasizing the comprehensive application of knowledge components, all amid rapid technological evolution [2–6]. Nevertheless, the current teaching model for IC-related courses tends to overemphasize theoretical principles and formula derivation, while neglecting the practical application and engineering context of circuit design. Moreover, it often fails to address the integrated application of knowledge components in real-world engineering scenarios. This leads to a lack of clear guidance and application-driven motivation in student learning, dampens their interest, and ultimately compromises learning outcomes. Therefore, how to cultivate high-level talents capable of "flexibly applying knowledge components in engineering practice" remains a critical issue for higher education institutions to explore.

Taking the course "Analysis and Design of Analog Integrated Circuits" as an example, this paper proposes a "New Engineering" curriculum development approach based on "Component Integration," aimed at cultivating high-level IC engineering talent. It seeks to explore new models, methods, and concepts for engineering education that bridge the gap between academia and society, theory and practice, and education and application. The goal is to develop outstanding engineering talents who possess both innovative spirit and practical ability, as well as capabilities in scientific discovery and engineering application. The proposed approach consists of three main dimensions: a teaching philosophy centered on the "Aggregation of theoretical elements" for imparting basic theoretical knowledge; a teaching methodology that constructs a multidimensional knowledge system through the "Dynamic deduction of performance elements", using the optimization of typical circuit performance as the main narrative thread; and an engineering capability cultivation method driven by the "Application elements aggregation" through engineering case studies.

2. Overall teaching philosophy and teaching methods

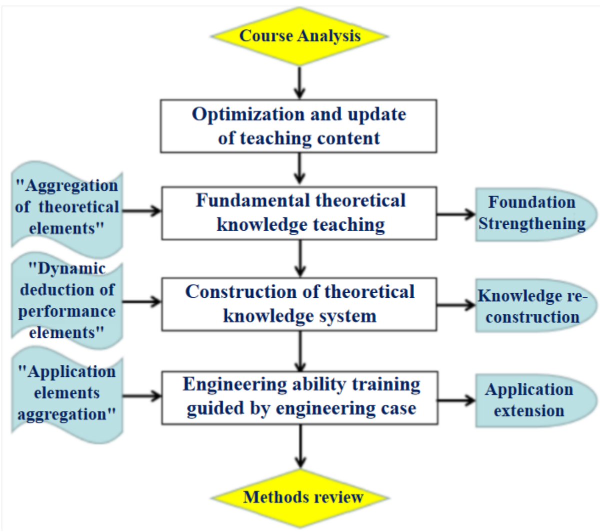

Figure 1. Overall teaching approach of "elements aggregation."

In order to achieve the ultimate teaching goal of cultivating innovative high-level talents in integrated circuits under the background of emerging engineering education, the teaching process of this course is divided into three stages: fundamental theoretical knowledge teaching stage, construction of theoretical knowledge system stage, and engineering ability training stage. The three stages are indispensable and interrelated. By adopting teaching methods such as "Aggregation of theoretical elements", "Dynamic deduction of performance elements", and "Application elements aggregation", the teaching objectives of strengthening the foundation, reconstructing the knowledge system, and expanding applications are achieved, respectively (**Figure 1**).

2.1. Optimization and update of teaching contents

The content of classic textbooks often lags behind the rapid advancement of integrated circuit technology, resulting in a training approach that fails to closely align with the technological forefront and real-world industrial practices. Given the swift pace of innovation in IC technology, it is essential to continuously update teaching materials with the latest knowledge, technological developments, and future trends in the field of electronics and information. Doing so ensures that talent cultivation remains relevant to societal needs, maintains the timeliness and advanced nature of the curriculum, introduces students to the current state and developmental directions of the industry, stimulates learning interest, enhances teaching outcomes, and broadens students' perspectives.

Therefore, in designing the course content, the teaching team has balanced foundational knowledge, engineering applicability, and contemporary relevance. By integrating the team's specialized technical expertise, outcomes from research projects, and ongoing tracking of the latest academic and industrial trends, the curriculum incorporates explanations and analyses of recent achievements, advanced design methodologies, and cutting-edge application cases in analog integrated circuits. Examples include the gm/Id methodology [7,8], near-threshold design techniques [9], EEG acquisition chips for biomedical applications [10,11], full-duplex transceivers for 5G communications [12,13], and AI chips [14,15]. Through these measures, the course maintains its relevance and advanced character, stimulates students' learning interest, and broadens their academic and professional horizons.

2.2. "Aggregation of theoretical elements" facing to fundamental knowledge teaching

Core knowledge elements form the foundation for both course learning and engineering application. These elements, in turn, are supported by fundamental theoretical concepts from prerequisite courses. Taking the analysis and calculation of the differential-mode gain of a fully-differential amplifier as an example, this knowledge element relies on foundational theories such as the Superposition Theorem and Thevenin's Theorem from earlier courses, and requires the integrated application of these fundamentals. Therefore, students' depth of conceptual understanding of these basic theoretical elements, as well as their retention of knowledge from prerequisite courses, directly impacts their learning outcomes.

However, due to insufficient mastery of knowledge elements and the gradual forgetting of content from earlier courses, students often face significant difficulties in comprehensively applying prior knowledge to analyze topics in current courses. To address this, the course integrates core foundational theory elements, such as KVL/KCL theorems and the Superposition Theorem from Fundamentals of Electric Circuits, and the s-domain transfer function from Signals and Systems, by developing micro-lecture videos and compiling comprehensive online resources. These materials provide targeted reinforcement of key knowledge components and guide students in applying them synthetically to analyze core topics of the course. Through this approach, the course strengthens foundational knowledge and cultivates students' ability to integrate and apply fundamental theoretical elements, thereby laying a solid foundation for subsequent instructional activities.

2.3. "Dynamic deduction of performance elements" facing to the construction of multidimensional knowledge system

In traditional teaching of analog integrated circuits, knowledge elements and various classic IC prototype circuits are often presented in a fragmented manner, with instructors seldom exploring the intrinsic connections between these components. However, by integrating engineering practice and deeply examining the historical progression of performance optimization in analog IC design, we can recognize that various types of integrated circuits are in fact part of an evolving system, one that is structured around the optimization of key performance metrics and exhibits a dynamic, deductive character.

Taking the common-gate amplifier (source follower) shown in **Figure 2** as an example, three circuit variants, the resistor-biased source follower, current-mirror-biased source follower, and PMOS-input source follower, can be understood as successive stages in an engineering effort focused on improving linearity. This optimization trajectory forms a clear deductive thread, where gains in linearity are achieved at the cost of other performance aspects such as output swing and drive capability, illustrating a distinct trade-off relationship.

In response, the course introduces a teaching methodology termed "Dynamic deduction of performance elements." This approach uses circuit performance optimization as the main narrative thread, dynamically illustrating how to enhance the performance of amplifier circuits in response to practical engineering challenges such as gain boosting, device sizing, output swing extension, and linearity improvement. These deductions are empirically validated through simulation using the Huada Jiutian Analog/Mixed-Signal IC Design Platform, with comparative simulation results presented visually for clarity.

Throughout the process, a series of guided questions is embedded to encourage step-by-step critical thinking and deeper engagement. By addressing real-world design problems, such as those related to gain, sizing, swing, and linearity, the instruction dynamically demonstrates performance optimization strategies for common-source amplifiers and other core circuits.

Furthermore, the course incorporates a central concept in IC design: trade-off analysis. Using fish-bone diagrams with hypothetical branches, students visually grasp how improving one metric (e.g., linearity in a single-stage amplifier) inevitably compromises others (e.g., gain or output swing). This visual and conceptual reinforcement helps students internalize the essential engineering mindset of design trade-offs. Through this dynamic, performance-oriented deduction process, a structured and coherent theoretical knowledge system for integrated circuits is effectively constructed.

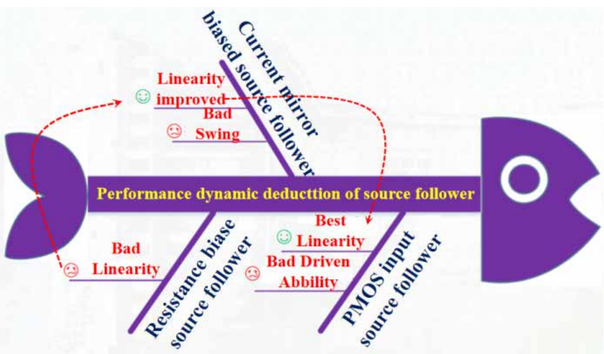

Figure 2. "Performance elements dynamic deduction" of the source follower.

2.4. "Application elements aggregation" guided by engineering cases

The course Analysis and Design of Analog Integrated Circuits aims to familiarize students with common analog IC architectures, master analog IC design processes and methodologies, and build a foundational theoretical knowledge system in the field of integrated circuits. The ultimate instructional goal is to equip students with a professional knowledge system that meets the demands of real-world engineering and to develop their ability to comprehensively apply, analyze, and solve practical engineering problems.

To this end, we propose an application-oriented teaching methodology termed "Application elements aggregation," which is driven by engineering cases. By selecting representative cases that not only cover key course knowledge elements but also reflect the forefront of IC scientific research and engineering applications, students are exposed to the complete "forward design" process of practical engineering examples through the use of EDA tools on a full-flow IC design platform. This approach immerses students in a highly visual and impactful learning experience, enabling them to grasp the full spectrum of application elements and engineering thinking specific to analog IC "forward design." Through the integration of fundamental theory and design elements in practical design contexts, students further consolidate their theoretical knowledge and elevate their engineering application capabilities.

As an example, consider the selected case study of a high-sensitivity wireless energy harvesting chip for wireless sensor networks. Driven by this engineering scenario, students analyze the working principles and performance metrics and decompose the chip into its constituent circuit blocks. From this, the most representative sub-block—the operational amplifier within the linear voltage regulator—is chosen as the focus for design training. First, students evaluate whether previously studied basic amplifier circuits meet the actual engineering requirements of the energy harvesting chip in terms of gain, output impedance, linearity, etc. This leads naturally to the introduction of the two-stage amplifier, followed by an in-depth analysis of its operating principles and design methods.

Based on this analysis, students conclude that the two-stage amplifier fulfills the practical requirements of the energy harvesting chip (**Figure 3**). Then, within an IC design virtual environment using the Huada Jiutian EDA platform, a domestic full-flow analog/mixed-signal IC design tool, the complete design flow of the two-stage amplifier is demonstrated in a realistic setting. Coupled with a structured, summary-oriented teaching approach, this immersive demonstration enables students to assimilate key analog IC design flow elements, core engineering concepts, and practical proficiency with the Huada Jiutian EDA tools, achieving a visually engaging and pedagogically effective experience.

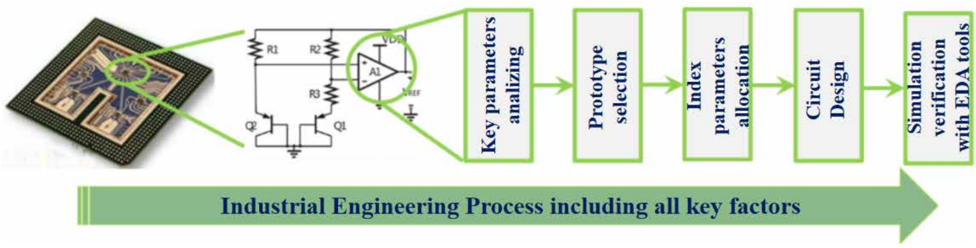

Figure 3. Example of "Application elements aggregation."

3. Conclusion

Taking the key foundational course in integrated circuits, Analysis and Design of Analog Integrated Circuits, as an example, this paper builds on the proposed "New Engineering" teaching and reform methodology centered on "Elements Integration," aimed at cultivating high-level engineering talent. Using the domestic Huada Jiutian EDA platform for full-flow analog/mixed-signal IC design as a bridge for forward design in practical engineering applications, we explore new pathways and mechanisms for achieving first-class teaching standards and developing a high-caliber teaching team. This effort aims to accumulate experience for further deepening educational reform and to cultivate multi-dimensional, high-quality engineering talents who are closely aligned with technological frontiers and industrial practices in the integrated circuit industry.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Research Group for the 2022 Integrated Circuit Design Talent Demand Report, 2022, China (Mainland) Integrated Circuit Design Talent Demand Report. China (Mainland) Integrated Circuit Design Talent Demand Report, visited on June 20, 2025, https://www.sgpjbg.com.cn/baogao/110404.html.

[2] Behzad R, 2024, Education of Chip Designers at a Large Scale: A Proposal [Society News]. IEEE Solid-State Circuits Magazine, 16(2): 76–83.

[3] Tsividis Y, Antoniadis D, 1982, A Multiproject Chip Approach to the Teaching of Analog MOS LSI and VLSI. IEEE Transactions on Education, 25(2): 48–53.

[4] Jorge M, Krzysztof H, Daniel A, et al., 2025, Tapeout-Oriented Strategies for Teaching Analog/Mixed-Signal IC Design and Implementation in Electrical Engineering Education. Proceedings of the 38th SBC/SBMicro/IEEE Symposium on Integrated Circuits and Systems Design (SBCCI): 1–5.

[5] Jorge M, Krzysztof H, Daniel A, et al., 2025, Tapeout-Oriented Strategies for Teaching Analog/Mixed-Signal IC Design and Implementation in Electrical Engineering Education. Proceedings of the 38th SBC/SBMicro/IEEE Symposium on Integrated Circuits and Systems Design (SBCCI): 1–5.

[6] Kinget P, 2023, Teaching IC Design: From Concepts to Testing a Fabricated Custom Chip. IEEE Solid-State Circuits Magazine, 15(3): 87–93.

[7] Zhang X, Wu Q, Wang Y, et al., 2023, Technology Generic Delta-Sigma ADC Design with gm/ID Methodology. Proceedings of the IEEE 17th International Conference on Anti-Counterfeiting, Security, and Identification (ASID): 105–109.

[8] Zhang X, Wu Q, Wang Y, et al., 2023, Technology Generic Delta-Sigma ADC Design with gm/ID Methodology. Proceedings of the IEEE 17th International Conference on Anti-Counterfeiting, Security, and Identification (ASID): 105–109.

[9] Ganguli T, Das S, De F, et al., 2025, Impact of the Threshold Voltage Variability of the Junctionless MOSFET on Digital Performances in Sub-Threshold Regime. Proceedings of the Devices for Integrated Circuit (DevIC): 914–918.

[10] Zhou T, Gao Z, Huang J, et al., 2021, Flicker Noise Analysis on Chopper Amplifier. Proceedings of the IEEE International New Circuits and Systems Conference (NEWCAS): 1–4.

[11] Kenji M, Daisuke K, Tetsuya H, 2024, 0.36 μW/Channel Capacitively-Coupled Chopper Instrumentation Amplifier in EEG Recording Wearable Devices for Compressed Sensing Framework. Japanese Journal of Applied Physics, 63(3): 03SP54.

[12] Du Y, Yang K, Chen N, 2023, Single Antenna and No Circulator Full-Duplex With 52 dB Wideband Self-Interference Suppression. IEEE Transactions on Circuits and Systems I: Regular Papers, 70(9): 3451–3460.

[13] Du Y, Chen J, Li G, 2022, Integrated Self-Interference Suppression for Single Antenna Full-Duplex Without Circulator. Proceedings of the IEEE Interregional New Circuits and Systems Conference (NEWCAS): 75–79.

[14] Zakaria T, Langi A, Sophian N, et al., 2025, Artificial Intelligence (AI) in Neurofeedback Therapy Using Electroencephalography (EEG), Heart Rate Variability (HRV), and Galvanic Skin Response (GSR): A Review. IEEE Access, 13: 133078–133112.

[15] Jafari M, Sadeghi D, Shoeibi A, et al., 2024, Empowering Precision Medicine: AI-Driven Schizophrenia Diagnosis

via EEG Signals: A Comprehensive Review from 2002–2023. International Journal of Speech Technology, 54(1): 35–79.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.