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Pedagogical Practice of Integrating VLSI Design Automation Tools into University-Level IoT Curriculum

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Abstract: With the rapid advancement of Internet of Things (IoT) technologies, there is an urgent need for universities to explore more effective teaching models in IoT engineering programs, particularly to address shortcomings in hands-on training and the disconnect between theoretical instruction and industry demands. Very-Large-Scale Integration (VLSI) technology, as one of the core components of IoT, plays a critical role in determining the performance and market competitiveness of IoT devices. The integration of VLSI design automation tools not only improves design efficiency but also provides intuitive and effective means for practical teaching. This study centers on CMOS semiconductor devices and constructs a radial knowledge framework encompassing "Device–Model–Circuit–System." By employing LTSPICE, a professional-grade simulation tool, the instructional content is visualized, enabling students to develop a deeper understanding of complex circuit principles and device characteristics. In addition, real industrial-grade SPICE models and fabrication process parameters—such as the 45 nm silicon-on-insulator (SOI) technology—are introduced to strengthen the link between academic instruction and practical engineering applications. Moreover, this research incorporates emerging technologies such as artificial intelligence, deep learning, and autonomous driving into instructional case studies, effectively enhancing student engagement, interest, and innovation capacity in practice-based learning environments.

Keywords: Very-Large-Scale Integration; Internet of Things Engineering Education; Linear Technology SPICE; CMOS; Deep learning; Radial Knowledge Framework

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1. Introduction

With the rapid development of Internet of Things (IoT) technologies, their extensive applications have permeated various sectors, including industry, agriculture, healthcare, and transportation, gradually forming a vast and interdisciplinary industrial ecosystem. As a technology-driven field, the fast-paced evolution of IoT demands a large number of highly skilled engineering professionals who possess both solid theoretical foundations and strong hands-on capabilities [1]. However, the current teaching models in IoT engineering programs at domestic universities generally suffer from insufficient practical training and a disconnect between theoretical instruction and industry requirements, leading to a talent gap that fails to meet enterprise expectations. Therefore, there is an urgent need for higher education institutions to explore innovative teaching approaches and practical methodologies to enhance instructional effectiveness and students' comprehensive practical abilities [2].

Very-Large-Scale Integration (VLSI) technology, as a key enabler within the IoT industrial chain, plays a decisive role in determining the performance and market competitiveness of IoT devices. The emergence and continuous advancement of VLSI design automation tools have provided substantial support for hardware design in the IoT domain, while also offering new pathways and perspectives for engineering education. These tools not only significantly improve design efficiency but also enable intuitive simulation and analysis, making complex circuit principles more accessible and comprehensible, thereby addressing the limitations of traditional teaching models, such as abstract theory and lack of practical engagement [3].

This study addresses the existing deficiencies and challenges in the teaching of university-level IoT engineering programs by placing VLSI design automation tools at the core. It investigates how these tools can be effectively integrated into IoT-related curricula. By incorporating industry-recognized design automation platforms such as LTSPICE, the study aims to establish a systematic learning pathway that bridges theory and practice, allowing students to grasp the fundamentals and methodologies of integrated circuit (IC) design while gaining familiarity with advanced industrial design standards and workflows. Furthermore, this research emphasizes the integration of emerging technologies—such as artificial intelligence, deep learning, and autonomous driving—into instructional case studies, thereby enhancing the modernity and applicability of the curriculum, stimulating students' interest in IC design, and improving their analytical and problem-solving capabilities in real-world engineering scenarios [4].

Through this teaching practice, the study seeks to address key issues in current IoT engineering education, including the theory-practice divide, outdated curriculum content, and insufficient practical skills among students. It further aims to develop a novel teaching model and methodology that not only improves instructional effectiveness but also cultivates high-quality talent aligned with industry demands [5]. Ultimately, the findings of this research will contribute valuable experience to the construction of IoT engineering courses in higher education and serve as a meaningful reference for educational reform in related fields.

2. Implementation plan for teaching support using VLSI design automation tools

2.1. Constructing a radial knowledge framework centered on CMOS devices

The foundational IoT hardware course positions CMOS semiconductor devices as the core of instruction, aiming to establish a comprehensive and in-depth radial knowledge framework based on the interconnection of "Device–Model–Circuit–System" [6]. This pedagogical model breaks away from the traditional isolated teaching of discrete knowledge points, instead organizing course content in a more systematic and integrative manner. First, by introducing device characteristics, students are enabled to intuitively understand the physical structure, operational principles, and performance parameters of CMOS devices. Second, through tightly linking theoretical modeling, students gain insights into how device models influence circuit behavior. Next, building upon these models, the course extends to practical circuit design and analysis, enabling students to master basic unit circuit design techniques and their real-world applications. Finally, the system-level construction of complex

IoT architectures based on these fundamental circuits is explored, helping students to grasp how theoretical knowledge is translated into practical systems.

Throughout this process, the use of VLSI design automation tools such as LTSPICE plays a critical role in supporting teaching practice. These tools offer robust simulation and analytical capabilities that visually present dynamic signal changes within circuits, assisting students in understanding abstract theories more clearly. This comprehensive and structured approach to knowledge development helps students form a solid conceptual foundation and achieve higher-level professional competence, significantly enhancing the effectiveness of the course.

2.2. Visualized instruction using LTSPICE simulation tools

Traditional instruction in semiconductor physics is often overly abstract, making it difficult for students to intuitively understand complex physical phenomena and circuit operations, which in turn reduces learning engagement and efficiency. To address this issue, this study advocates the use of LTSPICE as a simulation tool to support visualized instruction and enhance the presentation of theoretical knowledge [7]. LTSPICE is a powerful, industry-grade simulation platform featuring a highly intuitive graphical interface and real-time simulation capabilities, capable of accurately modeling actual circuit behavior.

In practical implementation, instructors use LTSPICE to design canonical CMOS circuit models, clearly demonstrating the structural characteristics and functional principles of devices. Students observe dynamic changes in node voltages and current waveforms during simulation, allowing them to visualize how theoretical concepts manifest in actual behavior. For instance, through simulation exercises involving CMOS inverters, differential amplifiers, and logic gates, students can clearly follow the circuit operation from the device level to the system level, deepening their understanding of how device performance impacts overall circuit functionality.

Additionally, the use of LTSPICE enables instructors to identify and explain issues students encounter during laboratory experiments in real time, thereby closely integrating theoretical learning with hands-on practice and enhancing students' problem-solving abilities [8]. Through this approach to visualized instruction, students not only develop a deep understanding of CMOS device fundamentals and circuit design principles but also cultivate engineering thinking and practical skills, laying a solid foundation for advanced coursework and future engineering applications.

2.3. Practical instruction with industrial SPICE models and process parameters

To ensure alignment between educational content and real-world industrial demands, this study incorporates industrial-grade SPICE models and process parameters, such as the 45 nm Silicon-on-Insulator (SOI) technology, into practical teaching using the LTSPICE simulation platform. Unlike traditional teaching methods, this approach allows students to work directly with device parameters and circuit models used in industry, leading to a deeper understanding of the sophistication and complexity of semiconductor manufacturing processes.

In practice, instructors design representative circuit case studies that guide students in conducting simulation-based analysis using industrial SPICE models. By observing node voltages, current waveforms, and circuit performance metrics under realistic process constraints, students gain insight into how fabrication parameters influence design outcomes. This method not only enhances students' theoretical understanding but also significantly improves their practical skills and ability to address real engineering challenges, ultimately fostering talent that better meets the demands of the semiconductor industry.

2.4. Integrating emerging technologies to stimulate student interest

To further cultivate student interest in VLSI design, this study integrates instructional content with cutting-edge technological applications, including artificial intelligence (AI), deep learning, and autonomous driving systems [9]. Through a case-based approach, students are introduced to real-world design needs of intelligent hardware chips, helping them recognize the critical role of IC design in modern IoT innovation. For example, in the context of autonomous driving, instructors may elaborate on core circuit components in self-driving chips and use simulation cases to explain the design principles and implementation strategies behind these high-tech systems.

Additionally, examples such as AI processors and deep learning accelerators are included to demonstrate how specific circuit architectures support the real-time execution of complex algorithms. This integration of practical, high-impact applications helps stimulate students' motivation and curiosity, while also enhancing their engineering mindset and capacity for innovative design.

3. Implementation plan and procedures

3.1. Curriculum development phase

The first year of this study focuses on curriculum development, specifically constructing a knowledge framework centered on CMOS devices and designing detailed instructional content based on this core [10]. In implementation, the teaching team will begin by reviewing the current syllabus for the foundational IoT hardware course, identifying key knowledge areas centered on CMOS semiconductor devices, and mapping their relationships with adjacent knowledge modules to construct a radial "Device–Model–Circuit–System" structure.

To ensure scientific rigor and comprehensiveness, the team will consult high-quality IoT and VLSI design textbooks and recent academic literature, incorporating industry needs to develop targeted teaching plans. Industrial-grade simulation software, LTSPICE, will be introduced as an instructional aid to design preliminary hands-on cases that integrate theoretical learning with practical simulation.

During the initial course delivery, instructors will use lectures and demonstrations to present the architecture and content of the knowledge network. Multiple teaching methods—including in-class interaction, group discussion, assignments, and simulation labs—will be employed to gather comprehensive feedback from students. In particular, during simulation sessions [11], students will be guided in using LTSPICE to perform basic CMOS circuit simulations, helping them visually comprehend core concepts.

Regular feedback and evaluation mechanisms will also be implemented, such as surveys and discussion sessions, to collect detailed student feedback on the knowledge framework and teaching practices. This feedback will be used to dynamically refine and improve the curriculum. Through this first year of exploratory practice, the teaching team will accumulate valuable experience and establish an initial, practical, and effective teaching methodology and content system, laying a solid foundation for future course enhancement.

3.2. Simulation practice phase

In the second year, this study will focus on in-depth circuit design practice by fully incorporating LTSPICE, an industrial-grade simulation tool, into teaching. This will enable students to strengthen their understanding of IoT hardware fundamentals through hands-on simulation experiences. The teaching team will further develop and refine simulation case studies, incorporating real process parameters such as the 45nm silicon-on-insulator (SOI) technology to ensure simulations closely reflect real-world industrial scenarios.

Students will be guided through the design and simulation of specific circuits. By closely observing node voltages, current waveforms, and circuit performance indicators, they will be led to discover and analyze practical design challenges and corresponding solutions. Additionally, technical lectures and seminars will be organized to help students master advanced simulation techniques and understand the nuances of modern process technologies.

Students will work in teams to complete a series of progressively challenging simulation projects, culminating in comprehensive project reports or papers. These deliverables will be used to evaluate their understanding and practical application skills. The teaching team will provide feedback and targeted suggestions to ensure students achieve meaningful progress and competence. Moreover, the teaching team will document and publish the outcomes of this year's simulation practice in educational research papers, summarizing both pedagogical experiences and the effectiveness of simulation-based instruction.

3.3. Curriculum refinement and dissemination phase

In the third year, the focus will be on synthesizing and optimizing the results of the previous phases to further refine the overall instructional framework for the IoT hardware foundation course. The teaching team will conduct a comprehensive analysis of prior achievements and remaining challenges, with particular attention to student feedback and actual instructional outcomes, to systematically improve the course structure.

This phase will result in a more stable and mature instructional model and curriculum architecture. Key deliverables will include a clearer and more coherent knowledge structure, more diversified and enriched simulation content, and case studies better aligned with real-world industry needs. The team will also author formal teaching reform papers, summarizing innovations in pedagogy, tool integration outcomes, and the enhancement of students' practical engineering skills.

In parallel, the research findings will be actively promoted through teaching conferences, academic seminars, and journal publications, encouraging adoption and adaptation by other universities with similar IoT-related programs. A final project report will be prepared, comprehensively summarizing the implementation process, core outcomes, and future application prospects. This will form a replicable and scalable teaching reform model, contributing meaningfully to the advancement of IoT education and its alignment with industry requirements (**Figure 1**).

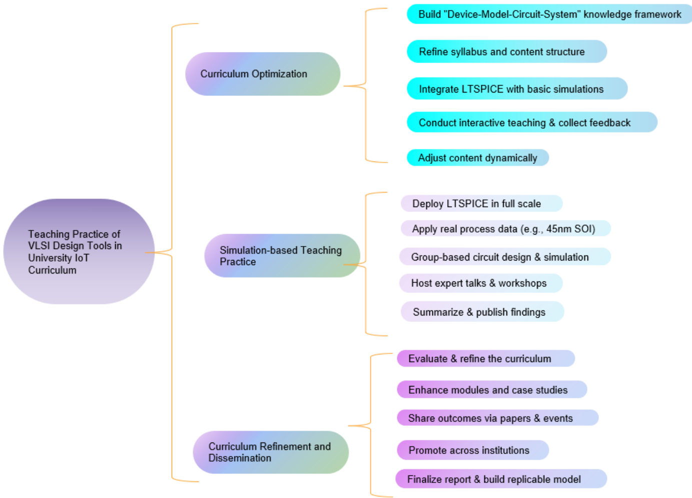

Figure 1. Flowchart of teaching practice using VLSI design tools in university IoT curriculum.

4. Conclusion

This study addresses the common challenges in current IoT engineering education at the university level, particularly the lack of practical training and the disconnect between theoretical instruction and industry demands. It proposes and implements an innovative teaching model centered on the use of Very-Large-Scale Integration (VLSI) design automation tools. By constructing a radial knowledge network focused on CMOS semiconductor devices, the study systematically integrates and optimizes instructional content for IoT-related courses.

Through the adoption of LTSPICE, an industrial-grade simulation platform, a series of intuitive and visualized teaching practices were conducted, significantly enhancing students' comprehension of complex circuit principles and their hands-on practical skills. Furthermore, by incorporating real industrial SPICE models and advanced process parameters, students gained deeper insight into the challenges and technical details of real-world design, substantially improving their professional competence and employment competitiveness.

In addition, the curriculum is closely aligned with emerging technologies such as artificial intelligence, deep learning, and autonomous driving. This integration has proven effective in stimulating students' learning interest and creative engagement, thereby significantly improving overall instructional outcomes.

Over three years of continuous implementation, the project is expected to yield a mature teaching model and practical instructional system. A series of academic papers on teaching practice and pedagogical innovation will be published, contributing a wealth of experience to educational reform. The outcomes of this study will provide valuable reference and practical guidance for the development of IoT engineering curricula in higher education, forming a scalable and transferable teaching reform model. Ultimately, it will promote continuous improvement in both the quality of IoT education and its alignment with evolving industry demands.

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