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# Teaching Practice of Implementing VLSI General Education in the Undergraduate Curriculum of University IoT Programs

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**Abstract:** With the rapid development of IoT technology, the Fundamentals of IoT Hardware course—one of the core subjects in university IoT programs—urgently requires innovation and improvement in both its content and teaching methodology. This paper, based on an educational reform project funded by the Hainan Provincial University Education Program, explores how to effectively implement general education on Very Large-Scale Integration (VLSI) design and manufacturing within the Fundamentals of IoT Hardware course. The study conducts practical teaching experiments through innovative instructional models, visualized presentation of semiconductor device structures and processes, integration of industrial-grade simulation tools, and the application of cutting-edge technologies. The objective is to stimulate students' innovative thinking and enhance their hands-on abilities. Finally, this paper summarizes the outcomes of implementing VLSI general education in the course and offers relevant suggestions for further educational reform.

**Keywords:** Internet of Things; Hardware fundamentals; VLSI; Teaching reform; Educational practice

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## 1. Introduction

With the rapid advancement of information technology, the Internet of Things (IoT) is gradually permeating all aspects of modern life, including smart homes, intelligent healthcare, industrial automation, and smart cities. Against this backdrop, hardware technology—serving as the crucial support for the "perception layer" and "control layer" of IoT systems—has become increasingly vital. In the core field of hardware design, Very Large-Scale Integration (VLSI) technology plays an indispensable role, forming the foundational pillar of modern electronic information technology development and industrial upgrading.

Currently, China is accelerating its strategic transformation from "Made in China" to "Intelligent

Manufacturing in China." At the national level, there is growing emphasis on key technologies such as chips and integrated circuits. University, as the main force in scientific innovation and talent cultivation, must keep pace with the times by aligning its education and teaching processes with the demands of industry. As one of the core courses in IoT engineering programs, Fundamentals of IoT Hardware is responsible for equipping students with essential skills such as sensor interface design, data acquisition, embedded systems, and circuit design. However, traditional teaching content and methods are increasingly unable to meet the new era's demand for compound, application-oriented electronic information talents [1].

In this context, how to scientifically and effectively incorporate VLSI general education into undergraduate IoT programs has become an urgent issue that warrants research and practice. VLSI design and manufacturing encompass a wide range of knowledge, including physics, circuits, and systems, and represent a frontier area of information technology. By appropriately introducing core concepts, key processes, and design flows from the VLSI field, students' professional horizons can be broadened, their interest in electronic design and system integration can be stimulated, and their interdisciplinary competence can be significantly enhanced.

This paper, based on the Hainan Provincial University Educational Reform Research Project titled "Reform and Practice of Teaching Methods for the Fundamentals of IoT Hardware Course under the Background of 'Intelligent Manufacturing in China,'" focuses on the application and implementation of VLSI general education within the IoT curriculum. The goal is to realize a closed-loop teaching structure—from device fundamentals to modeling and simulation, and finally to system-level applications—through systematic reforms in both content and methodology. This effort aims to create a new paradigm of course design aligned with industrial development trends and responsive to student growth needs, offering valuable insights and practical experience for the modernization of IoT curricula.

## 2. Design and practical application of VLSI general education in the Fundamentals of IoT Hardware course

In the curriculum system of IoT engineering programs, the Fundamentals of IoT Hardware course plays a critical role in helping students establish a foundational understanding of how sensing devices connect to embedded systems. However, traditional teaching models often suffer from outdated content, weak alignment with cutting-edge technologies, and low student engagement. To better support the cultivation of multidisciplinary engineering talent under the strategic initiative of "Intelligent Manufacturing in China," this project constructs a new teaching model integrating VLSI general education by addressing four key dimensions: curriculum content, pedagogical methods, technical tools, and industry alignment [2].

### 2.1. Structural optimization and reconstruction of teaching content: Building a radiating knowledge network of "Device–Model–Circuit–System"

In traditional electronics courses, content is often delivered in a linearly stacked manner, typically following the sequence of "device theory → circuit design → system implementation." Although logically rigorous, this structure often lacks systemic interconnections between knowledge points. As a result, students frequently find the knowledge fragmented and difficult to integrate, leading to outcomes such as "learning without understanding" and "knowing without mastery."

To break through this bottleneck, this project restructured the content system of the Fundamentals of IoT Hardware course, placing the MOSFET device at the core to build a multilayer, radiating knowledge network based on the logic of "Device–Model–Circuit–System." This structure transforms the content delivery from isolated “points” to a system-wide “plane,” thus optimizing the organization of knowledge.

This framework emphasizes the intrinsic logical relationships among knowledge components. It guides students from learning basic semiconductor principles to gradually building electrical models, analyzing circuit-level applications, and finally understanding system-level architecture. For example, with MOSFET as the entry point, students first master its operational principles, carrier behavior, and gate-control characteristics. Then, by introducing SPICE modeling techniques, they learn how MOSFETs are represented in circuit simulations and performance analyses. Next, by designing essential circuits such as common-source amplifiers, CMOS inverters, and differential pairs, students grasp the core logic of both analog and digital circuits. Finally, the course connects these principles to real-world IoT system applications—such as embedded SoCs, ADC/DAC converters, and power management modules—helping students integrate fragmented knowledge into complete engineering systems, thereby achieving a closed-loop learning process.

By constructing a four-in-one educational logic framework of “Device–Model–Circuit–System” (**Figure 1**), this project has effectively restructured the course content in a systemic manner. On one hand, it enhances the coherence and completeness of knowledge, avoiding issues in traditional teaching such as imbalance or partial understanding. On the other hand, it establishes a cognitive bridge for students from foundational knowledge to engineering applications, laying a solid theoretical and technical groundwork for future careers in smart hardware development, embedded systems, and integrated circuit design [3].

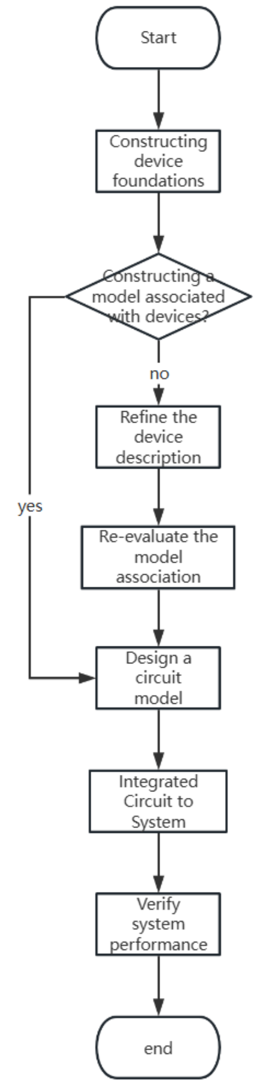


**Figure 1.** Teaching logic flowchart: Device–Model–Circuit–System

## 2.2. Reform of content presentation: Weakening physical theory, strengthening visualization and interactive experience

Students in IoT engineering programs typically focus on system integration, embedded development, and engineering practice, and often lack systematic training in semiconductor physics as taught in microelectronics disciplines. Traditional teaching methods frequently present concepts such as energy band structure, carrier concentration statistics, work function, and Fermi level through mathematical derivations and abstract physical illustrations. While these methods help explain the essence of devices, they often present significant cognitive barriers for students without a microelectronics background, resulting in reduced engagement and motivation.

To address this, the course adopts the principle of “weakening formula derivation, strengthening intuitive perception” by employing visual, dynamic, and interactive methods to enhance students’ understanding and engagement with complex physical processes. In terms of teaching content, the course intentionally de-emphasizes intricate semiconductor physics derivations and instead emphasizes visual demonstrations of core processes such as CMOS device structures, PN junction behavior, and diffusion/drift mechanisms.

By incorporating 3D modeling and animation technologies, abstract micro-scale devices are transformed into visual, engineering-oriented models. For example, when explaining MOSFET structures, interactive 3D models display the composition of the gate, source, and drain. During the explanation of ion implantation and doping, animations illustrate changes in carrier distribution, while simulation waveforms and graphical tools demonstrate dynamic potential variations—helping students understand the relationships among structure, electric field, and behavior.

The course also develops video resources and interactive courseware on a micro-learning platform, focusing on visual micro-modules for key concepts such as PN junction diffusion and carrier drift. These modules are accompanied by interactive quizzes that facilitate autonomous learning both in and outside the classroom. Feedback shows that after completing these modules, students' understanding of concepts such as MOSFET operating regions, electric field distribution, and carrier behavior improves significantly. Instant feedback from quizzes also helps instructors better adjust teaching strategies [4].

In summary, the reform in content presentation—focusing on visualization and interaction—not only improves the overall quality of teaching and student satisfaction but also provides a replicable model for introducing semiconductor general education into non-microelectronics engineering disciplines.

### 2.3. Technological upgrade of teaching tools: Introducing LTSPICE simulation for engineering training

In traditional electronics courses, students typically learn about basic circuit behavior through paper-based analysis or manual calculations. While this approach fosters analytical thinking, it becomes inefficient and lacks intuition when dealing with complex circuit systems, falling short of modern engineering requirements for modeling, simulation, and verification.

To address this gap, the project integrates LTSPICE—an industrial-grade circuit simulation platform—into the experimental components of the course as a key tool in a triadic "learn–practice–verify" engineering training model. LTSPICE, developed by Analog Devices, offers a high-performance simulation engine, a comprehensive component library, and a flexible scripting interface, making it widely used in analog and mixed-signal circuit design.

The course builds tasks around representative analog modules such as NMOS inverters and common-source amplifiers. With SPICE model configuration, students can observe I-V characteristics under various biasing conditions, helping them understand the cognitive chain from "physical modeling → circuit behavior → system function."

To strengthen real-world application, experiments include multi-parameter sweeps and power supply noise analysis, training students to design robust circuits under non-ideal conditions. For senior students, the course introduces script writing and macro-modeling with LTSPICE, encouraging them to develop deeper insights into how device-level parameters affect circuit performance. For instance, students manually define a PMOS model based on 45 nm CMOS process parameters and construct a custom inverter module.

Course evaluations show that most students highly value the LTSPICE sessions, noting that the simulation tools significantly enhance their intuitive understanding of circuit behavior and provide a solid foundation for future work in electronic design.

The integration of LTSPICE into the Fundamentals of IoT Hardware course not only establishes a vital platform for practicing VLSI general education but also promotes comprehensive development in professional competence, engineering awareness, and innovation capabilities through real-world tool application.

### 2.4. Industry alignment of teaching content: Presenting the evolution of VLSI technologies from a general education perspective

With the rapid development of information technology and smart devices, VLSI technology has become a cornerstone of modern science and engineering. However, students in IoT engineering—particularly those without a microelectronics background—often lack a clear understanding of the semiconductor industry and the technological evolution involved.

To address this, the course introduces the development history and future trends of VLSI technology, highlighting the transformations and challenges of the semiconductor industry [5]. It begins with an overview of traditional bulk CMOS processes, including their working principles, application scopes, and performance advantages. It then explores the transition to FinFET (Fin Field-Effect Transistor) technology, emphasizing its benefits in improving integration density and reducing power consumption. Finally, it introduces cutting-edge structures such as nanowire gate-all-around FETs (GAA-FETs), discussing challenges to Moore's Law and the scaling limits of manufacturing processes.

This general education approach enables students to gain a broad understanding of semiconductor process history and progress—especially in addressing integration and power efficiency at nanoscale dimensions. The course also incorporates real-world technology roadmaps from companies like TSMC and Intel, showcasing innovations in 7 nm, 5 nm, and future 3 nm process nodes, helping students understand how VLSI technology tightly integrates with industry needs.

Furthermore, the course emphasizes the critical role of VLSI in real-world applications by analyzing its use in AI accelerator chips, edge computing modules, and SoCs for smart devices. This shift from component-level learning to system-level understanding deepens students' appreciation of the technology.

By establishing a three-pronged cognitive framework—"Device–Industry–System"—students not only gain insight into fundamental VLSI principles but also understand their broad application in engineering. This enhances students' sense of purpose in learning and fuels their enthusiasm for technological innovation. Through deep alignment with industry development, this course provides students with both a solid theoretical foundation and strong technical support for future careers in IC design, smart hardware development, and IoT system engineering.

## 3. Teaching practice and outcome evaluation

The integration of VLSI general education into the Fundamentals of IoT Hardware course is not only reflected in the reform of teaching content and methods, but also in a series of concrete explorations and experiments in teaching practice. Through the organization and implementation of instructional activities, this chapter elaborates on the applied teaching tools and strategies used throughout the reform process, along with the corresponding evaluation methods. Key aspects include assessments of student learning attitudes and outcomes, feedback and improvement of experimental components, and survey results on student participation and satisfaction with the course reform.

### 3.1. Implementation of teaching practice

In line with the project design, the teaching practice was implemented across multiple dimensions. First, the course structure closely follows the integrated framework of "Device–Model–Circuit–System." Beginning with fundamental theories of semiconductor devices, the course gradually transitions to circuit analysis, simulation, design, and system-level applications, ensuring logical coherence between each knowledge module. This organization helps students build a solid theoretical foundation while developing practical engineering skills.

To further enhance hands-on experience, the course integrates the LTSPICE simulation tool into laboratory sessions, engaging students in circuit design and analysis tasks. By simulating voltage-current characteristics of basic circuits such as NMOS inverters and common-source amplifiers, students gain both theoretical insights and verification skills. Advanced tasks such as multi-parameter sweeps and power supply noise analysis are incorporated to cultivate students' engineering mindset and prepare them for real-world challenges [6].

To stimulate autonomous learning, the course utilizes modern resources such as video micro-lectures and interactive animations, enabling students to visually explore CMOS device operations and fabrication processes. Embedded quizzes reinforce understanding, while real-time feedback mechanisms allow for continuous instructional adjustment, ensuring a feedback loop that enhances engagement and learning effectiveness.

## 3.2. Teaching effect evaluation and analysis

To scientifically evaluate the effects of the course reform, the project employed both quantitative and qualitative methods across several dimensions—student knowledge acquisition, engineering skill development, attitude changes, and innovation capacity improvement.

Knowledge acquisition was assessed through midterm and final exams, as well as in-class quizzes. These evaluations focused on applied problem-solving, requiring students not only to understand theoretical concepts but also to apply them in practical circuit design. For instance, in the final exam, students were asked to use LTSPICE to simulate circuits and analyze their performance based on a given schematic.

Results indicated a significant improvement in students' understanding, particularly in circuit analysis and simulation. Moreover, students demonstrated enhanced engineering and technical competencies through the use of LTSPICE in laboratory sessions. Evaluations of lab reports and hands-on performance showed that students developed stronger independent thinking and could independently adjust and optimize circuit parameters, reflecting real progress in engineering capabilities.

Surveys and interviews conducted after the course revealed that most students approved of the reformed content and methodology. They found the curriculum both challenging and engaging, especially valuing the simulation-based instruction. Many students reported that hands-on use of LTSPICE helped them better understand the principles and applications of VLSI.

During the innovation and integration segment, students were tasked with designing and optimizing circuit systems based on their learned knowledge and real-world engineering contexts. Evaluation results showed that many students demonstrated strong innovation awareness and problem-solving abilities, proposing design improvements and applying new simulation models to real-world scenarios—highlighting the course's role in fostering creativity and innovation [7].

## 3.3. Teaching feedback and suggestions for improvement

While the reform achieved notable success, several areas for improvement were identified through teaching feedback and evaluations. First, although the simulation and experimental components were effective, students expressed a strong need for deeper integration of theory and practice. It is recommended to expand the number of experimental projects and include more complex circuit design tasks to further develop students' engineering skills.

Second, current interaction is mainly achieved through micro-lectures and animations. To enhance student participation and motivation, additional interactive formats such as group discussions and collaborative design projects are recommended. Finally, while the course features rich case studies and industry-oriented content, further strengthening ties with industry developments is essential. This could include inviting industry experts for guest lectures or organizing visits to semiconductor manufacturers and IC design companies to deepen students' understanding of real-world VLSI applications [8].

## 4. Conclusion

This project explores the feasibility and effectiveness of introducing VLSI general education into the Fundamentals of IoT Hardware course. Centered around a "Device–Model–Circuit–System" knowledge framework, the course transitions students from fundamental device theory to circuit analysis, simulation, and system-level application—ultimately enabling them to apply theoretical knowledge in real-world engineering contexts.

By integrating the LTSPICE simulation platform, the course significantly enhanced students' practical abilities in circuit design and verification. Additionally, modern teaching tools such as micro-lectures and interactive animations sparked student interest and enriched the learning experience [9].

Evaluation results indicate substantial improvement in students' understanding of VLSI concepts and engineering skills, particularly in circuit analysis, design, and simulation. Students responded positively to the content and teaching methods, noting that the reformed course placed greater emphasis on hands-on practice and real-world relevance. This, in turn, stimulated their innovation and problem-solving abilities.

Nonetheless, certain aspects—such as the quantity of hands-on projects and the diversity of interactive formats—still require enhancement. Future improvements will focus on expanding practical components, diversifying interactive teaching methods, and strengthening industry integration to improve students' industrial awareness and readiness.

Looking forward, as VLSI technology continues to evolve, the Fundamentals of IoT Hardware course will keep pace with technological trends by incorporating more diverse teaching tools and methods. The course will deepen its collaboration with industry by inviting experts for lectures and mentorship, and by providing more industry-oriented learning opportunities. Furthermore, it will continuously refine its content by adding more challenging design tasks and system-level projects to enhance students' comprehensive engineering competence.

Through ongoing pedagogical innovation and reform, this course aspires to equip students with a solid technical foundation and broader career prospects—contributing to the cultivation of high-quality professionals for the nation's semiconductor and IoT industries [10].


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## Disclosure statement

The authors declare no conflict of interest.

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