

Project-Driven Teaching Innovation for Fundamental Courses of Computer-Related Majors with Self-Developed Experimental Devices

Ping Shao

School of Computer Science and Software Engineering, Zhaoqing University, Zhaoqing 526061, Guangdong, China

Abstract: Addressing the disconnection between theory and practice, the mismatch between experimental devices and textbooks, and the fragmentation of chapter-level experiments in computer fundamentals courses for computer-related majors, this paper proposes a project-driven teaching innovation model using the first-year course "Computer Cognition and Practice" as a case study. Built upon the self-published textbook "Computer Cognition and Training" (Tsinghua University Press, 2022) and a set of self-developed experimental devices, the model adopts a "One Device Throughout" design-the same devices run through most chapters with progressively deepening applications-and constructs a four-stage progressive cognitive path: cognition, verification, design experience, and innovation experience. The devices serve dual functions as a soldering quality inspection tool and a microcontroller cognition experimental platform, and incorporate extended AI experiences such as speech recognition. Teaching practice shows that the model effectively improves students' practical ability and professional learning interest. The textbook has been adopted by more than 30 universities nationwide with a cumulative circulation of 1,800 copies, and the outcome won the first prize of university-level teaching achievement awards. The model is replicable and scalable, providing a systematic reference for practical teaching reform in local universities.

Keywords: Project-Driven Teaching, Self-Developed Experimental Devices, Computer Fundamentals, Practical Cognition.

1. Introduction

As introductory courses for lower-division students in computer-related majors, computer fundamentals courses play a foundational role in establishing professional cognition and cultivating engineering practice interest. However, practical teaching in such courses currently faces several common dilemmas: excessive theoretical instruction with insufficient hands-on experience, costly and rigid commercial equipment that poorly matches textbook content, fragmented chapter-level experiments lacking a unified connecting carrier, and the growing contradiction between compressed class hours and cognitive cultivation needs [1].

In the traditional model, textbooks and experimental devices often exist in a disconnected state: textbooks focus on systematic theoretical exposition while devices complete verification operations following fixed procedures, lacking deep coupling and collaborative design. Meanwhile, teaching reform outcomes often lack simultaneous support from formally published textbooks and supporting devices, hindering large-scale promotion.

Taking the professional fundamentals course "Computer Cognition and Practice" as an example, this study constructs a project-driven teaching innovation model centered on the "One Device Throughout" concept. The objectives are: (1) achieving deep integration between the self-compiled textbook and self-developed devices; (2) designing a progressive practical cognitive path from component cognition to AI innovation experience; (3) validating the model's effectiveness through multi-cohort practice; and (4) forming a replicable and scalable reform plan for local universities.

The theoretical significance lies in integrating project-driven learning theory with the "One Device Throughout" design, enriching the theoretical construction of practical

teaching models. The practical significance lies in providing an integrated "textbook + device + model + evaluation" solution, offering a reference path for local universities to improve lower-division students' professional cognition and practical interest under limited resources.

2. Theoretical Background

Project-Driven Learning (PDL) originates from constructivist learning theory and the "Learning by Doing" philosophy [2–4]. Its core is using real projects as carriers, allowing students to actively construct knowledge while completing project tasks. Unlike the traditional "theory first, practice later" model, PDL emphasizes that project tasks guide the teaching process and theoretical learning serves task completion. In computer fundamentals courses, PDL can effectively stimulate lower-division students' learning motivation and cultivate problem-solving awareness.

However, existing PDL research mostly adopts "single-chapter projects" or "end-of-term comprehensive projects," lacking systematic design that runs the same project carrier through most chapters [5]. The "One Device Throughout" concept proposed in this study-using the same devices as a unified carrier throughout the course with progressively deepening applications-is precisely a deepening and expansion of PDL theory.

Additionally, the collaborative design of textbooks and experimental devices is key to improving practical teaching quality [6]. In the traditional model, textbook compilation and equipment procurement are often independent processes, resulting in textbook tasks that cannot be completed on existing equipment or wasted overcapacity. With the popularization of open-source hardware such as Arduino and STM32, an increasing number of universities independently develop teaching devices to reduce costs and improve adaptability [7], yet systematic cases integrating self-

developed devices with formally published textbooks throughout the teaching process remain scarce.

This model also adopts an Outcome-Based Education (OBE) evaluation framework [8, 9], designing assessment indicators with cognitive objectives as the guide. OBE emphasizes student-centeredness, outcome orientation, and continuous improvement, aligning with the goal of cultivating lower-division students' practical cognitive abilities.

3. Construction of the Project-Driven Teaching Model

3.1. Teaching Philosophy and Overall Architecture

The teaching philosophy is summarized as: strengthen practical training, simplify theory, reduce class hours, and drive with tasks. Specifically: strengthening practical training means practical class hours account for no less than 70%, with hands-on tasks in every chapter [10]; simplifying theory means following the "sufficient and practical" principle, integrating abstract concepts into project contexts and avoiding pure theoretical indoctrination; reducing class hours means completing introductory cognitive cultivation in fewer hours through content integration-merging content from multiple traditional courses such as computer assembly and maintenance, electronic technology, and practical network technology to form the distinctive course "Computer Cognition and Practice" [11]; driving with tasks means using the "One Device Throughout" design to guide practical teaching tasks, where students complete progressive tasks on the same device in different chapters and actively acquire knowledge through hands-on practice.

The model follows five principles: "One Device Throughout" (unified carrier through most chapters), progressive deepening (device application depth increases chapter by chapter), student-centeredness (cognitive outcomes as the guide), textbook-device collaboration (synchronous planning), and open extensibility (open-source schematics and code).

The overall architecture comprises "one core, dual foundations, four stages, and five modules": project-driven teaching with "One Device Throughout" as the core; the self-compiled textbook and self-developed devices as dual foundations; cognition, verification, design experience, and innovation experience as four progressive stages; and textbook content, device functions, project tasks, teaching implementation, and evaluation feedback as five modules. The system operates in a closed loop of "project objectives → textbook content → device support → project implementation → evaluation feedback → continuous improvement."

3.2. Self-Compiled Textbook and Self-Developed Experimental Devices

The textbook "Computer Cognition and Training," edited by the author and colleagues, was published by Tsinghua University Press in August 2022 (ISBN: 978-7-302-61263-6) [12]. It adopts a five-chapter modular structure, each featuring "cognition tasks + practical operations" deeply integrated with device application depth. Chapter 1 covers computer hardware and software fundamentals, with the project task of component cognition corresponding to the device's role as a "cognition carrier." Chapter 2 covers manual circuit board soldering, with the project task of soldering work inspection corresponding to the device as an "inspection tool." Chapter

3 covers circuit schematic design and microcontroller program control, with the project task of circuit design cognition and microcontroller programming experience corresponding to the device as a "development experience platform." Chapters 4–5 cover computer network and security fundamentals and common LAN services, with comprehensive application experiences such as network communication verification and serial communication. The textbook also integrates ideological and political education through cases such as domestic supercomputers and the HarmonyOS operating system.

The self-developed devices, designed following low-cost, open-source, and textbook-integrated principles, serve as a unified carrier for project-driven teaching throughout the course. The hardware includes an STC51 microcontroller core board, an 8×8 LED dot matrix display module, an LCD12864 display screen, a key array of five independent keys, an ASR-PRO speech recognition module, a relay output module, a USB download interface and serial communication circuit, as well as an acrylic enclosure with a pluggable module structure. The core board and functional modules are separable, supporting connection of student-soldered LED dot matrix modules or self-designed microcontroller modules. The supporting software includes 13 progressive experiment codes, compilation and download tools, and an instruction manual. The 13 experiments are divided into three levels: basic (Experiments 0–5, LED dot matrix control including full lighting, row-by-row/dot-by-dot lighting, static and scrolling character display), intermediate (Experiments 6–10, LCD display and serial communication), and comprehensive (Experiments 11–13, key-controlled matrix inspection, speech-controlled relay, and integrated speech+key+LED experiments). All schematics and code are open-source, facilitating replication and secondary development by peer institutions.

3.3. "One Device Throughout" Design and Four-Stage Cognitive Path

The core innovation is the "One Device Throughout" design: the same set of devices serves as a unified project carrier, assuming different roles in different chapters with progressively deepening applications. Students complete a full introductory practical chain from cognition to innovation experience around the same hardware project, avoiding experimental fragmentation.

Stage 1-Cognition (Chapter 1): The device serves as a "cognition carrier." Students observe the device, identify core components (microcontroller, LED dot matrix, resistors, capacitors, diodes, transistors, keys, relays, speech module), and understand their functions.

Stage 2-Verification (Chapter 2): The device serves as an "inspection tool." Students solder an 8×8 LED dot matrix board, connect it to the device for automatic row-by-row and dot-by-dot quality inspection, and identify and repair cold solder joints, short circuits, or component damage. The instant feedback reduces teachers' guidance burden and cultivates self-inspection habits.

Stage 3-Design Experience (Chapter 3): The device serves as a "development experience platform." Level A is circuit schematic design cognition, where students learn simple circuit schematic design methods and draw partial schematics and PCB board diagrams of the device, such as the LED dot matrix drive circuit and key interface circuit, understanding the design logic of the device hardware. Level B is

microcontroller programming experience, where students write simple C language programs, download them to the STC51 microcontroller via USB, and visually display the running results through the 8×8 LED dot matrix, such as row-by-row or dot-by-dot lighting, static character display, and scrolling text display. This stage establishes preliminary cognition and experience of circuit design and microcontroller programming, while deepening understanding of the device's row-by-row and dot-by-dot inspection principle from Chapter 2.

Stage 4-Innovation Experience (extended session): The device serves as an "AI innovation experience platform." Students use the ASR-PRO module for speech command recognition and training (keyword wake-up, online model generation), speech-controlled LED dot matrix display, speech-controlled relay switching (simulating smart home scenarios), and comprehensive projects integrating speech, keys, LED matrix, and relay, exposing first-year students to cutting-edge AI technology and cultivating innovation awareness and inquiry interest.

The four-stage path aligns with constructivist learning theory and Vygotsky's Zone of Proximal Development, guiding students to expand cognitive boundaries by progressively increasing task difficulty. The textbook-device collaboration is reflected in four dimensions: content collaboration (project tasks integrated with device functions), process collaboration (device runs through pre-class, in-class, post-class, and assessment), resource collaboration (textbook, schematics, code, and manuals form a complete resource package), and iterative collaboration (textbook reprints and device upgrades planned synchronously).

The evaluation system adopts OBE [8, 9]: process evaluation (60%) includes task completion, four-stage performance, and classroom participation; summative evaluation (40%) includes comprehensive project defense and basic theoretical tests. Evaluation data drives the closed loop of continuous improvement.

4. Implementation and Effect Evaluation

The model is implemented in the School of Computer Science and Software Engineering at the author's university, covering first-year students in Computer Science and Technology, Software Engineering, Network Engineering, and related majors. The implementation timeline spans 2019–2026: course prototype and lecture notes (2019), teaching iteration and device prototype development (2020–2021), textbook publication and first-version device finalization (2022), second-version device upgrade with AI speech recognition (2023–2024), and multi-university promotion and outcome summarization (2025–2026). Teaching organization includes concise theoretical lectures, device project practical training, open laboratory, and project defense.

The textbook has been adopted by more than 30 universities nationwide, including Yanshan University, Hubei University of Technology, Guangdong Ocean University, Guangzhou University, Shenzhen Technology University, and multiple vocational colleges. Peer institution feedback indicates clear project main lines, complete device support, significant improvement in students' hands-on ability, and natural integration of ideological and political education.

Effect evaluation covers four dimensions: practical ability, learning interest, knowledge mastery, and teaching

satisfaction [5]. Evaluation methods include analysis of device project task completion quality, course satisfaction questionnaires, student interviews, and subsequent course grade tracking. Students show an obvious growth curve across the four stages: component identification accuracy exceeds 95%; first-time soldering pass rate increases from approximately 60% to over 85%, with significantly enhanced self-inspection and troubleshooting awareness; the 13 progressive experiments have an average completion rate of 90%; and approximately 70% of students complete personalized comprehensive experience projects. Tracking data shows that students who completed this course achieve higher average grades in subsequent courses such as "Microcontroller Principles and Applications" and "Computer Networks" compared to previous cohorts, indicating improved practical foundation and subsequent learning ability.

Course satisfaction exceeds 90% across the teaching model, experimental devices, and practical components, with approximately 80% of students willing to use the open laboratory for self-practice. Student interviews indicate that the "learning by doing" model makes abstract computer professional basic knowledge intuitive and perceptible, the self-developed device's instant inspection feedback enhances the sense of learning achievement, and AI speech recognition extension experiences stimulate interest in exploring artificial intelligence. Some students stated that through this course they transformed from "knowing nothing about computer hardware" to "being able to personally build and debug a simple small electronic system," with significantly enhanced professional learning confidence. The outcome won the first prize of the 2024 university-level teaching achievement award, with one formally published textbook [12], self-developed devices with 13 experiment codes, and one approved university-level teaching reform project.

5. Discussion and Conclusion

The model's advantages are mainly reflected in six aspects: first, the "One Device Throughout" design provides a clear project main line, with the same device serving as a unified carrier connecting most chapters, enabling students to form systematic professional cognition and effectively avoiding experimental fragmentation; second, the progressive design is scientifically sound, with the four stages of "cognition-verification-design experience-innovation experience" aligning with lower-division students' ability formation patterns; third, the deep integration of textbooks and experimental devices fundamentally solves the "two-skin" disconnection problem between textbooks and experiments; fourth, the integration of AI elements, with speech recognition extension experiences exposing fundamentals-course students to cutting-edge technology, stimulates innovation awareness; fifth, low cost and high adaptability, with the self-developed device costing far less than commercial experimental boxes and being fully open-source, facilitating replication and secondary development; sixth, replicability and scalability, with the integrated "textbook + device + model + evaluation" solution being easily portable.

The model also faces some challenges in the promotion process: device mass production, maintenance, and upgrading require funding and technical support; differences in class hour arrangements and student foundations across universities require localized adaptation; teachers need an adaptation period for the project-driven model, and teacher

training is a necessary component for promotion; and this study currently relies mainly on the author's university data, requiring more rigorous large-scale empirical research. The implications for local universities are: reconstructing teaching content with cognitive outcomes as the guide, reducing practical teaching costs with self-developed devices, and improving teaching systematicness with the "One Device Throughout" design. Future work includes device iterative upgrading (incorporating more AI/IoT experiments), online virtual experiment platform construction, teaching standard formulation, and provincial/national teaching achievement award applications.

In conclusion, taking "Computer Cognition and Practice" for first-year students as an example, this study constructs a project-driven teaching innovation model centered on the "One Device Throughout" concept. Built upon the dual foundations of the self-published textbook "Computer Cognition and Training" and self-developed experimental devices, the model achieves four-stage progressive cognitive cultivation from component cognition to AI speech recognition innovation experience. Multi-cohort practice and adoption by more than 30 universities demonstrate that the model effectively improves students' practical ability and professional learning interest. The model is replicable and scalable, providing a systematic reference for local universities to improve practical teaching quality in computer fundamentals courses under limited resource conditions.

Acknowledgments

This work was supported in part by the Higher Education Teaching Reform Project of Zhaoqing University (Grant No. zlgc2024089)

References

- [1] Zhang, Y., Cao, L., & Wang, W. (2022). Analysis and countermeasures of teaching pain points in basic computer courses under the background of emerging engineering education. *J. Anqing Normal Univ. (Natural Sci. Ed.)*, 28(4), 99-102.
- [2] Hu, H., & Xia, H. (2023). Main characteristics, learning sequences and teacher actions of project-based learning from the perspective of the third space. *Global Education*, 52(12), 120-128.
- [3] Thomas, J. W. (2000). *A review of research on project-based learning*. Autodesk Foundation.
- [4] Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice-Hall.
- [5] Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *Int. J. Educ. Res.*, 102, Article 101586.
- [6] Ke, Q., Fang, Y., & Zhai, Y. (2023). Innovation and practice of 'dual-coordination' industry-education integration cultivation model for engineering professional degree postgraduates. *Res. Higher Educ. Eng.*, (3), 53-58.
- [7] Dong, X., Ma, R., & Wang, J. (2023). Design of an experimental teaching platform for the working mechanism of intelligent agricultural equipment based on open-source hardware. *Exp. Technol. Manage.*, 40(4), 162-167.
- [8] Spady, W. G. (1994). *Outcome-based education: Critical issues and answers*. American Association of School Administrators.
- [9] Li, Z., & Wang, Z. (2021). Outcome-based curriculum teaching design. *Higher Educ. Dev. Eval.*, 37(3), 91-98.
- [10] Wu, Y. (2018). Building China's 'golden courses'. *China Univ. Teaching*, (12), 4-9.
- [11] Zhong, D. (2017). Connotation and actions of emerging engineering education construction. *Res. Higher Educ. Eng.*, (3), 1-6.
- [12] Shao, P., et al. (2022). *Computer cognition and practical training*. Tsinghua Univ. Press.