

AI-empowered Smart Teaching Reform of Embedded System Courses for Disciplinary Competitions and Industrial Needs

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Abstract. Against the background of AI-empowered education, to better implement the Ministry of Education's guideline of adopting a student-centered philosophy and comprehensively enhance talent cultivation capacity, this paper takes the course *Principles and Applications of Embedded Systems* for the electronic information engineering major at Dongguan City University as a case study, and explores a smart hierarchical project-based teaching reform path guided by disciplinary competitions and aligned with cutting-edge industrial demands. Since 2022, the original teaching content has been optimized by designing graded project tasks, using intelligent-assisted learning tools, and implementing dynamic process assessment. Classroom practice demonstrates that the updated teaching content and mode can effectively stimulate students' learning enthusiasm. Achievements from the National Undergraduate Embedded Chip and System Design Competition (China) further verify that this teaching reform can better adapt to the demands of the embedded industry and the requirements of disciplinary competitions. It significantly improves students' engineering practice ability as well as innovative thinking and teamwork competence. This research also provides a valuable reference for the AI-empowered teaching reform of embedded system courses in similar private undergraduate universities.

Keywords: Embedded system courses, Disciplinary competition, Smart teaching reform, Private undergraduate universities.

1. Introduction

Artificial Intelligence (AI) is recognized as a critical general-purpose technology of the Fourth Industrial Revolution, with major economies competing in policy planning, R&D investment, and industrial application. However, its practical deployment depends on Embedded Technology for real-time interaction with physical systems. In China, particularly in the manufacturing hub of Dongguan, the urgency of *Principles and Applications of Embedded Systems* as a key enabler of intelligent manufacturing is especially prominent. To meet the urgent demand for embedded talent, Dongguan City University, a private undergraduate institution in the Guangdong-Hong Kong-Macao Greater Bay Area, focuses on cultivating high-quality applied talents. It promotes industry-school exchanges to align curricula with industrial needs, and encourages student participation in national embedded system design competitions, establishing a "competition-driven, competition-integrated education" model to enhance engineering practice capabilities.

Effective curriculum teaching is central to cultivating applied embedded engineers. However, the course *Principles and Applications of Embedded Systems* integrates hardware, software, and system knowledge, characterized by strong theory, high practical demands, and rapid technological iteration, posing significant challenges to traditional teaching approaches. International studies, including Wang Yang's computer-supported project-based learning (PBL)^[1], Knoblauch C.'s digital PBL research^[2], Rios et al.'s PBL application^[3], Galuh A. et al.'s PBL-STEM integration^[4], Joseph T.'s bioethics PBL study^[5], and Meng Nanxi et al.'s multi-case analysis of PBL e-learning platforms^[6], all demonstrate the effectiveness of project-based learning. Domestically, Huang W. et al.'s hierarchical and diversified project model at East China University of Technology^[7], Liu Taoli and Zhang Jian's CDIO (Conceive, Design, Implement, Operate) based approach^[8], Zhang Xiaoheng and Gong Youlong's OBE-oriented personalized and hierarchical teaching model^[9], and

Kang Yanping and Huang Peng's OBE-based practical teaching reform^[10] have also achieved notable results.

Although traditional PBL and CDIO models are widely used in engineering education, they are difficult to replicate directly in local private undergraduate universities due to challenges such as students' weak academic foundations, low motivation, and varying regional industrial demands. Moreover, most PBL models tend to adopt a homogenized project difficulty level, often operating within a unified instructional framework where all students work on the same project or problem and follow similar steps to complete learning tasks. This makes it difficult to accommodate individual differences among students, and the instructional arrangement remains stuck in a "learn first, do later" model. At the same time, embedded technology evolves rapidly while course content lags behind, leading to a disconnect between learning and application. To address this, the curriculum reform directly incorporates industrial needs and academic competition standards by transforming real enterprise cases and technical challenges from competitions into teaching projects. It adopts a structured hierarchical design that assigns differentiated project tasks based on students' varying levels of ability—those with weaker foundations work on basic projects, while more capable students take on competitive challenges. This approach not only protects students' learning confidence but also helps identify and cultivate top talents. Teaching content is no longer organized as a linear progression of textbook knowledge; instead, it is driven by the goals of solving real-world problems and gaining recognition in academic competitions. By shifting from supply-side to demand-driven instruction, the reform ultimately aims to cultivate applied engineering talents who are ready to work immediately upon graduation. In summary, grounded in the industrial needs of Dongguan's smart manufacturing sector and guided by academic competitions, this curriculum reform employs a hierarchical project-based teaching model with customized content and progressively challenging tasks, effectively addressing the prominent issue of large disparities in students' foundational knowledge.

2. Analysis of teaching Status and Reform Motivation

2.1 Curriculum Orientation and Students' Learning Situation Analysis

Aligned with the talent training objectives of Dongguan City University's electronic information engineering program and the industrial demands of Dongguan and the Greater Bay Area, this study optimizes embedded system course content and builds systematic teaching resources. Using hierarchical project-based teaching, it strengthens students' practical innovation, comprehensive application competence in embedded design, and cultivates teamwork and communication skills through collaborative projects.

Principles and Applications of Embedded Systems is a core compulsory course for third-year undergraduates, with prerequisites including C Programming, Digital Circuits, and Microcontrollers. However, students in private undergraduate universities have a weak foundation, insufficient knowledge, fear of complex theories, and job-hunting pressure. Learning abilities are polarized: top students gain experience from competitions, while struggling students cannot handle basic programming. Meanwhile, the gap between limited experimental resources and the rapid evolution of embedded technology is widening. This tension, combined with the course's high-level and challenging nature, makes the traditional teaching model inadequate for current talent training needs. As a result, teaching the course poses a great challenge to private undergraduate universities. Deepening its teaching reform and developing a course system tailored to both student characteristics and regional industrial demands have become urgent priorities for improving applied talent cultivation.

These conditions render traditional teaching inadequate. Thus, advancing teaching reform and exploring a system tailored to student characteristics and regional industry demands is urgent for improving application-oriented talent training quality.

2.2 Analysis of the Current Teaching Status of Embedded System Courses

The current embedded course teaching faces four prominent problems. First, regarding the choice of development approaches, traditional register-level development is difficult and prone to causing students' fear. Our university has gradually shifted to standard peripheral library and HAL library development to lower the learning threshold and improve teaching efficiency. Second, the teaching content fails to keep pace with industrial technology iteration and ecosystem development. The curriculum mostly focuses on single-platform teaching of traditional MCUs (such as STM32), with insufficient coverage of emerging technologies such as the rise of domestic MCUs, RTOS, low-power communication, and edge AI, failing to meet enterprises' demand for multi-platform versatile talents. Third, the practical teaching model does not align with the highly engineered nature of the discipline. Experimental projects are mainly isolated verification experiments lacking full-process project training involving system analysis, hardware-software co-design, debugging, and optimization. There is also an imbalance between emphasizing software over hardware or vice versa, resulting in fragmented knowledge systems among students. Fourth, the single teaching model cannot accommodate students' differentiated needs. Unified teaching progress and project difficulty leave weaker students struggling to keep up while stronger students feel under-challenged, leading to low overall teaching effectiveness. There is an urgent need to transition toward personalized and project-based teaching.

3. Construction and Implementation of Hierarchical Project-Based Teaching Mode for Disciplinary Competitions and Industrial Demands

To better adapt to the learning ability of undergraduates in private universities and improve their proficiency in embedded development technologies required by the industry, this course takes the National Undergraduate Embedded Chip and System Design Competition and National Undergraduate Electronics Design Contest as the starting point. Centering on embedded development tasks closely linked to industrial cutting-edge technologies in the competitions, a project-based teaching mode tailored for disciplinary competitions and industrial demands is established. This mode adheres to the philosophy of "student-centered, project-carried and practice-driven". Its implementation framework consists of the following three modules.

3.1 Restructuring Teaching content for Disciplinary Competitions

By closely tracking industrial frontiers and talent demands, we take the competition topics and key technical points of authoritative events including the National Undergraduate Embedded Chip and System Design Competition and Guangdong Provincial Electronic Design Competition as the guideline for updating teaching content. For instance, in response to the growing focus on AI, Internet of Things, motor control and other fields in recent competitions, relevant technical modules are dynamically incorporated into course project design. As shown in Fig. 1, circuit construction and algorithm verification are carried out using computer simulation and development software such as JLCPCB EDA, MDK, and STM32CubeMX, ensuring that teaching content keeps pace with industry development and enhancing the timeliness and engineering practicality of instruction.

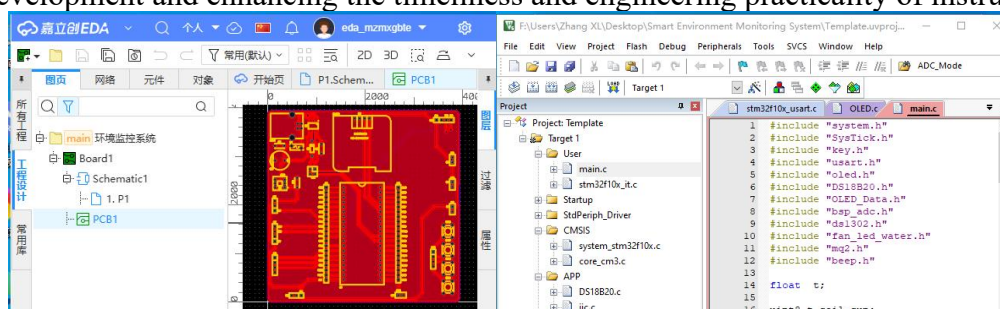


Fig. 1 Computer simulation and development platform

On this basis, the project-based teaching adopted in this teaching reform is designed to address the features of embedded system courses, namely abstract theories and strong practicality. It restructures the teaching approach that prioritizes engineering application while appropriately simplifying the explanation of fundamental principles. By embedding knowledge points into typical project tasks, utilizing computer simulation and development software for circuit design and functional verification, and conducting teaching through systematic and hierarchical project decomposition, this approach not only strengthens the cultivation of students' engineering practical capabilities and complies with the training objectives for application-oriented talents, but also effectively relieves students' fear of complex theories, and boosts their learning initiative and sense of achievement.

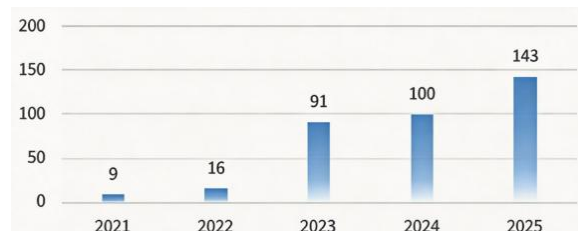


Fig. 2 Participation comparison in embedded competitions for telecom students (past 5 years)

As shown in Fig. 2, the number of students majoring in electronic information engineering participating in embedded system competitions has been steadily increasing over the past five years, demonstrating a positive trend of year-on-year growth. This not only reflects the appeal of such competitions in enhancing students' engineering competence, but also provides a practical basis for the dynamic updating of course content.

3.2 Promoting Curriculum Development Through Effective Integration of Industry and Education

To address the problems of outdated course content and the gap between students' practical engineering capabilities and actual corporate requirements, the "dual-teacher model" has been applied in the embedded design course. Students receive joint guidance from university teachers and senior engineers from enterprises such as Guangdong Yueqian Technology Co., Ltd. and Shenzhen Xinyingda Technology Co., Ltd. to complete practical projects. Driven by real industrial projects, the curriculum modules have been restructured. Authentic product development tasks are decomposed and transformed into teaching cases and a project library used across multiple semesters, covering practical resources such as intelligent flower watering systems and intelligent environment monitoring systems. Over the past three years, the dual-teacher model has been fully implemented in the Embedded System Design and Production course, with lectures delivered by enterprise instructors accounting for 25% of the total class hours.

Meanwhile, a diversified process-oriented evaluation system with enterprise participation has been introduced. Enterprise engineers act not only as joint instructors to provide real-world cases and technical guidance, but also, more importantly, as core evaluators together with university teachers throughout all assessment procedures. Instead of merely focusing on the functional demonstration of finished works, the evaluation criteria cover multiple dimensions including project innovation, standard engineering practices, industrial feasibility of technical schemes and teamwork performance. This mechanism enables real-time feedback and closed-loop adjustment of teaching quality, ensuring that talent cultivation objectives are dynamically aligned with the demands of local enterprises. Consequently, it helps cultivate high-caliber embedded talents with systematic innovation capabilities who can well meet the requirements of regional industries.

3.3 Design of Graduated Project Tasks

3.3.1 Hierarchical teaching

Based on the reconstructed framework of industry-education integration, refined teaching reforms have been carried out within the course. A hierarchical project teaching system is implemented, which consists of three dimensions, as shown in Fig. 3.

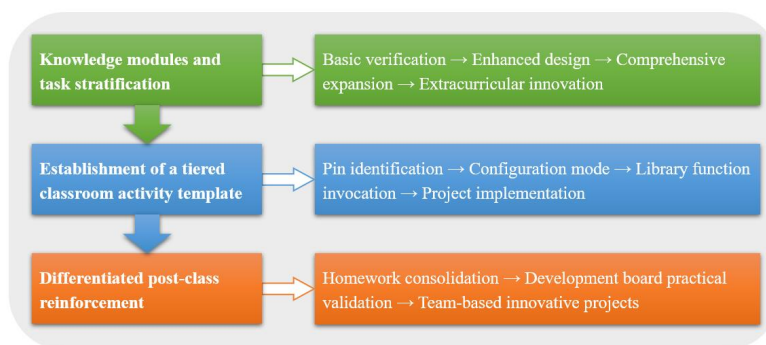


Fig. 3 Implementation of hierarchical teaching

First, knowledge modules and tasks are stratified. Teaching content is organized around peripheral devices including GPIO and USART. Four progressive task levels are designed for each module to form a clear competency ladder. In this way, students with different learning foundations can set suitable learning goals and achieve personalized development. Second, classroom activities are standardized with unified templates. Taking introductory courses such as GPIO Initialization as examples, we design logically connected hierarchical classroom activities. Adopting project-based and heuristic teaching approaches, we focus on guiding students to follow standard embedded development specifications, overcome learning difficulties, and gradually establish core thinking modes as well as gain a sense of achievement in embedded development. Third, differentiated post-class reinforcement is implemented. Three tiers of after-class tasks are developed, together with flexible supporting resources such as AI programming tools. These arrangements cater to diverse learning demands from basic knowledge reinforcement to exploratory innovation, and extend learning beyond the classroom.

3.3.2 Building a student community for embedded technology

Apart from developing an interest-driven personalized project library to offer flexible learning options, the curriculum improvement also optimizes the talent cultivation mechanism for outstanding students. Elite learners are assigned supervisors to engage in in-depth scientific research or enterprise projects. Meanwhile, peer learning is promoted by establishing an embedded technology association to form a sustainable learning community. Students are encouraged to set up interdisciplinary and cross-grade project teams and gain access to the college's embedded laboratory. A mentorship system where senior students guide newcomers is implemented to pass down project experience and technical know-how. Furthermore, a series of comprehensive projects with social value are systematically designed to guide students to reflect on the social ethics and responsibilities behind technologies.

4. Effects and Exploration of Hierarchical Project-Based Teaching

Practice has shown that the hierarchical project-based teaching method effectively addresses instructional issues arising from students' varying skill levels, enabling differentiated instruction. By focusing on practical application while streamlining theoretical content rather than eliminating it, this approach lowers the learning barrier and boosts students' overall interest and completion rates.

4.1 Students' Awards in Disciplinary Competitions

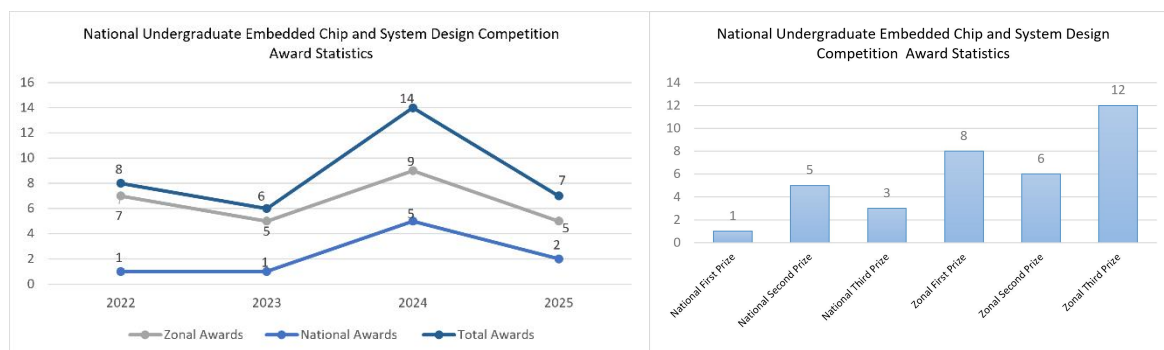


Fig. 4 Statistics of awards in National Undergraduate Embedded Chip and System Design Competition (2022–2025)

Restricted by limited resources and funding in private universities, we have established an interactive mechanism integrating competitions, courses and practical training since the launch of this curriculum. The number of student participants has increased year by year, and students' practical capabilities have been greatly improved. The award-winning rate ranks high among peer institutions. Students majoring in electronic information engineering have won more than ten national awards and dozens of provincial awards in embedded-related competitions. Specifically, they have obtained 9 national awards and 26 district-level awards in the National Undergraduate Embedded Chip and System Design Competition (China), totaling 35 awards. Fig. 4 presents the statistics of awards since participation began in 2022. The university has continuously won national awards for several consecutive years, including 1 First Prize and 5 Second Prizes at the national level. In 2024, a record high of 5 national awards was claimed.

From the perspective of award structure as shown in Fig. 5, high-level awards dominate the national competition results, with first prizes accounting for 11% and second prizes for 56%, reaching a combined total of 67%. Notably, second prizes alone account for more than half of all national awards. This indicates that the reformed curriculum system has effectively enhanced students' core competitiveness. Meanwhile, third prizes account for only 33% of national awards, significantly lower than the 45% observed at the zonal level. This suggests that practical teaching standards have been aligned with national evaluation requirements, effectively filtering out low-quality entries and ensuring the overall quality of participation.

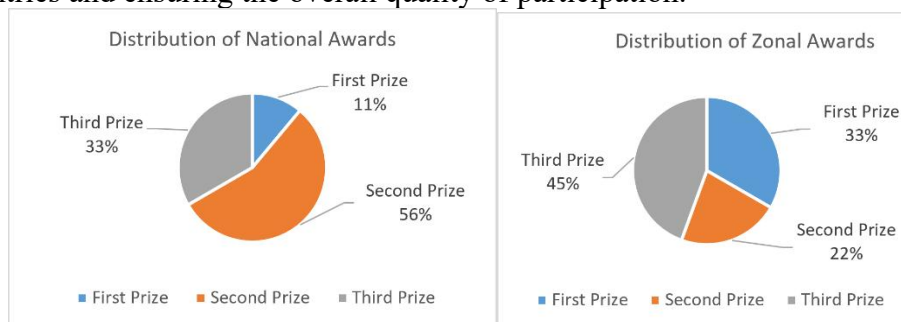


Fig. 5 Comparison chart of award level structure between national and zonal competitions

According to the competition data from 2022 to 2025 presented in Table 1, the university demonstrated sustained improvement at both the zonal and national levels. The number of participating teams generally increased, with the zonal award rate rising from 70% in 2022 to 90% in 2024, indicating that the curriculum and practice reforms effectively enhanced students' overall competitiveness. Notably, all teams that advanced to the national competition over the four years received national awards, maintaining a 100% success rate—strong evidence of the reform's effectiveness in cultivating high-level talent. In 2024, the university achieved record highs across all

indicators: 10 teams participated in the zonal competition, 9 won awards, and all 5 teams that advanced to the national competition won awards. Overall, the data provides strong evidence that the integrated mechanism of embedding competitions into coursework and practice significantly enhances students' practical and innovative abilities, demonstrating that high-quality talent cultivation is achievable in private institutions even under resource constraints.

Table 1. Statistics and winning rates of zonal and national competitions (2022-2025)

	2022	2023	2024	2025
Number of Participating Teams (a)	10	8	10	10
Number of Teams Winning Zonal Competition (b, $b \leq a$)	7	5	9	5
Zonal Competition Winning Rate (b/a)	70%	62.5%	90%	50%
Number of Teams Advancing to National Competition (c)	1	1	5	2
Number of Teams Winning National Competition (d, $d \leq c$)	1	1	5	2
National Competition Winning Rate (d/c)	100%	100%	100%	100%

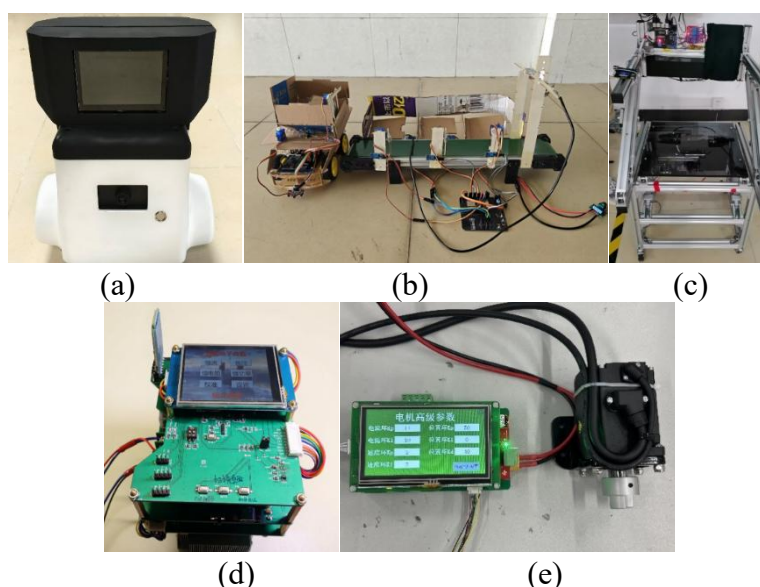


Fig. 6 Students' award-winning works. (a) Smart AI childcare and education assistant robot. (b) Intelligent object sorting system. (c) Smart chair for elderly and disabled care. (d) Intelligent electronic load. (e) Novel industrial brushless servo drive

Fig. 6 displays some of the students' award-winning works. Compared with ordinary embedded course projects, these works are no longer simple functional verification experiment results, but have effectively addressed practical pain points in daily life, such as the smart AI childcare and education assistant robot(a), the intelligent object sorting system(b), and the smart chair for elderly and disabled care (c). Ordinary projects are often limited to building functional modules with conventional technical approaches. In contrast, award-winning works fully consider industrial reliability requirements and possess the foundation for transitioning from the laboratory to real-world deployment, as exemplified by the intelligent electronic load(d) and the novel industrial brushless servo drive(e). Furthermore, award-winning works generally integrate cutting-edge AI technologies, demonstrating strong engineering thinking and commercial awareness—an important innovation of this educational reform. In addition, the award-winning outcomes are reused in graduation projects and other initiatives, enabling iterative development of works and forming a project talent pipeline.

4.2 Breakthrough Achievements in the Intel Cup

In 2024, our university received its first official invitation to participate in the Intel Cup National University Electronic Design Competition — Invitation Tournament for Embedded System. Centering on the competition theme "AI Everywhere", we adopted the Intel Nezha processor provided by the organizer and developed a multi-functional companion learning device for children integrated with ChatGPT and deep learning technologies, which is the Smart AI Childcare and Education Assistant Robot shown in Fig. 6(a). The entry ranked first in the Southern Division in the preliminary round. Competing with teams from many well-known universities in the national final, it finally won the National Second Prize. The award certificate bears the signatures of Academicians Guan Xiaohong and Kuang Dingbo, as shown in Fig. 7. Remarkably, this marks the first time a private undergraduate university in China has achieved such an honor in this competition.



Fig. 7 Award certificate

4.3 Curriculum Evaluation Effect

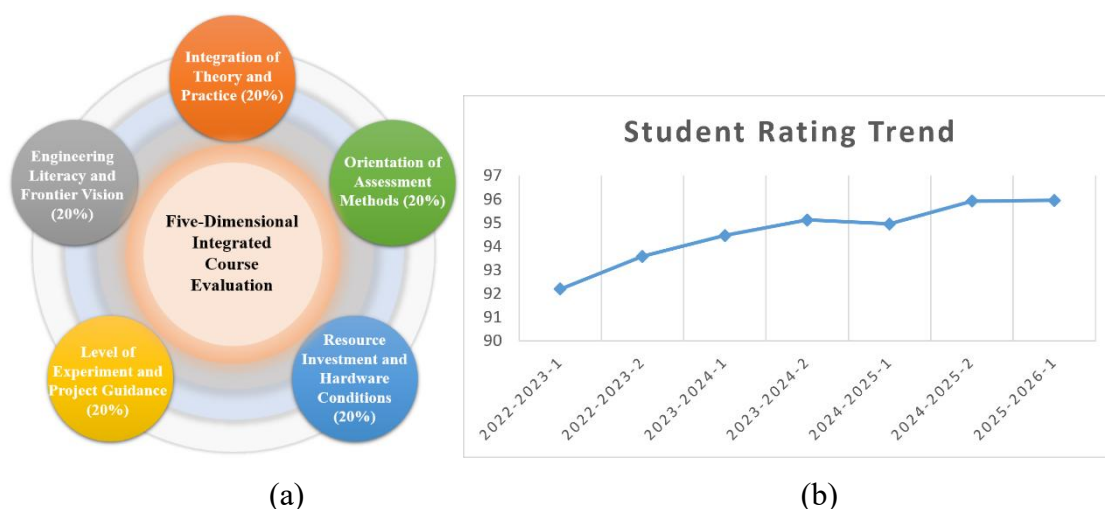


Fig. 8 Course evaluation. (a) Five-dimensional integrated course evaluation. (b) Student rating trend

Breaking the limitations of traditional single-dimension evaluation, the curriculum has established a quality feedback mechanism for embedded system courses from two perspectives: student assessment and teacher evaluation. The student assessment focuses on process-oriented evaluation of course projects, including student self-evaluation and joint assessment by university

and enterprise instructors. The curriculum evaluation mainly reflects students' overall satisfaction with course organization and teaching arrangements. This study innovatively proposes a five-in-one evaluation indicator system. Assessments are carried out from five dimensions: integration of theory and practice, engineering literacy and frontier vision, level of experiment and project guidance, resource investment and hardware conditions, and orientation of assessment methods. Each dimension accounts for 20% of the total weight, as shown in Fig. 8(a). The system not only examines students' knowledge mastery, but also lays emphasis on the cultivation of their engineering capabilities, innovative thinking and industry adaptability. It realizes dynamic monitoring and continuous improvement of the whole teaching process.

Table 2. Teacher classroom teaching quality scores from student ratings (on a 100-point scale)

Semester	Score from Student Evaluations	Number of Students
2022-2023-1	92.198	49
2022-2023-2	93.589	38
2023-2024-1	94.471	49
2023-2024-2	95.13	48
2024-2025-1	94.96	96
2024-2025-2	95.931	59
2025-2026-1	95.96	57

Table 2 presents the teacher classroom teaching quality evaluation data provided by the academic affairs system. Since the initiation of the teaching reform in 2022, the evaluation scores for the author's embedded systems course (with approximately 400 students) have consistently remained above 92 points, achieving a seven-semester average of 94.61 points. As the reform progressed, the scores exhibited a clear stepwise upward trend, as shown in Fig. 8(b). These results validate the effectiveness of the embedded course teaching reform pathway driven by subject competitions and oriented toward industrial demands. Integrating competition content into course instruction and restructuring practical components based on industry needs not only enhances the relevance and practicality of teaching but also significantly improves students' recognition of classroom teaching quality.

5. Conclusion

Aimed at cultivating application-oriented talents in private undergraduate universities, the teaching reform of embedded system courses has become imperative. This paper presents a smart teaching reform scheme for embedded system courses tailored to disciplinary competitions and industrial needs. By aligning with industrial requirements, adopting hierarchical project design, introducing intelligent-assisted learning tools, and emphasizing full-cycle practical training, the scheme effectively tackles the challenges posed by diverse student foundations and rapid technological iteration. The experimental results indicate the significant effectiveness of the proposed reform scheme. This teaching model not only enhances the pertinence and effectiveness of instruction, but also fosters high-caliber embedded professionals equipped with practical skills, innovative thinking and a strong sense of social responsibility who meet the demands of the new era. It also provides valuable references for the curriculum development of engineering disciplines in private undergraduate institutions.

Acknowledgements

This work was supported in part by the Dongguan City University General Project of Higher Education Teaching Reform Project under Grant 2024yjg055; in part by the 2025 Guangdong Provincial Universities Youth Innovation Talent Program Project (China) under Grant 2025KQNCX146.

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