Research on Teaching Innovation and Practice of Electrical and Electronic Technology Course Based on the CGI Concept

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Abstract. Against the backdrop of the global technological revolution, traditional electrical and electronic technology teaching faces problems such as the disconnection between theory and practice, insufficient cultivation of innovative capabilities, and inefficient evaluation systems. This study proposes the CGI (Center-Guide-Integrate) teaching concept, which takes students as the center and is guided by the three-dimensional dual guidance of knowledge and skills, curriculum-based ideological and political education, and industrial demand adaptation. It aims to achieve the four-dimensional triple integration goals: integration of online and offline teaching, integration of theory and practice, integration of process and outcome evaluation, and integration of industry-education collaborative empowerment. Based on constructivist and CDIO engineering education concepts, the proposed concept designs teaching strategies including learning situation diagnosis, task decomposition, curriculum-competition integration, and project-driven practice. A teaching practice was carried out with "combinational logic circuit design" as a case study. Through random grouping, an experimental group (CGI mode) and a control group (traditional mode) were set up, and a controlled experimental design with pre-test and post-test was adopted to verify the effectiveness. The results show that the average score of theoretical knowledge of students in the experimental group increased by 12.3%, the project completion rate increased by 35.7%, the number of innovative works grew by 42%, 89.2% of students could quickly adapt to basic engineering positions in enterprises, and the enterprise satisfaction with students' practical abilities reached 91.5%. This study provides a theoretical framework and practical path for the teaching reform of basic engineering courses, and is of great significance for improving the quality of engineering talent cultivation.

Keywords: CGI; Electrical and Electronic Technology; Blended Teaching; Class-Competition Integration; Industry-Education Collaboration

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1 Introduction

Electrical and Electronic Technology is a core compulsory course for multiple engineering majors, undertaking the task of cultivating students' engineering literacy and practical innovative abilities. Against the backdrop of the rapid development of technologies such as artificial intelligence, the society's demand for high-quality engineering talents is increasingly urgent. However, the traditional teaching mode is plagued by drawbacks such as passive student learning, the disconnection between theoretical teaching and practical training, and a single evaluation method.

Exploring innovative teaching concepts and strategies has thus become the key to teaching reform. The construction and implementation of the CGI teaching philosophy can effectively promote the integration of theory and practice, improve talent training quality, and hold significant theoretical and practical value.Foreign researches on the teaching reform of Electrical and Electronic Technology started early, with explorations on models such as project-driven teaching and online-offline blended teaching (e.g., the CDIO engineering education mode[1] and flipped classroom mode). Nevertheless, these foreign reform models are not well adapted to the teaching environment of universities in China.Domestic studies have focused on online teaching resource construction, blended teaching design, experimental teaching reform and curriculum ideological and political integration, which have achieved certain results. Yet, they still have limitations: most focus on single links such as teaching content or methods rather than systematic overall design; the connection between teaching innovation and talent training objectives is not close; the evaluation system is imperfect, with insufficient emphasis on process-oriented and competency-based evaluation.Industry-education integration mostly remains superficial, lacking specific and operable collaboration models and effectiveness evaluation criteria; experimental designs are often deficient in pre-tests and rigorous random grouping, making it difficult to ensure the causal validity of the conclusions.

2 Theoretical Basis and Connotation of the CGI Teaching Concept

2.1 Theoretical Basis

Constructivist Learning Theory. Constructivist learning theory holds that knowledge is not passively accepted by students, but actively constructed by students in the process of interaction with the environment[2]. The CGI teaching concept, which takes students as the center, is consistent with the core viewpoint of constructivism. By designing phased tasks and autonomous learning activities, students are guided to actively explore and construct knowledge, thereby improving their autonomous learning ability and problem-solving ability.

CDIO Engineering Education Concept. The CDIO engineering education concept emphasizes integrating the entire process of product conception, design, implementation and operation into teaching to cultivate students' comprehensive engineering ability[5]. The CGI teaching concept, with knowledge and skills as the guidance, realizes the integration of theory and practice through project-driven teaching, which is the inheritance and development of the CDIO concept. It helps students understand the application of theoretical knowledge in engineering practice and improve their engineering literacy.

Formative Evaluation Theory. Formative evaluation theory holds that evaluation should not only focus on learning results, but also attach importance to the learning process, and promote students' learning and development through timely feedback and adjustment. The CGI teaching concept integrates process evaluation and result evaluation, and adopts a multi-dimensional evaluation system, which meets the requirements of formative evaluation. This system can comprehensively reflect the process of students' learning and the development of their abilities, and provide a basis for teaching improvement[3].

2.2 Connotation of the CGI Teaching Concept

The CGI teaching concept is an innovative teaching concept constructed based on the analysis of the current teaching situation of Electrical and Electronic Technology and the demand for engineering talent training. It includes three core elements: "one center, three-dimensional dual guidance, and four-dimensional triple integration".

(1) One center: Student-centered. It emphasizes respecting the dominant position of students in the learning process, focusing on students' learning needs and ability development, and designing teaching activities and evaluation systems around students' growth.

(2) Three-dimensional dual guidance: Taking "knowledge and skills+curriculum-based ideological and political education + industrial demand" as the three-dimensional core, forming a dual guidance education logic. On the one hand, it focuses on the adaptation of professional knowledge and skills teaching to industrial needs, closely following the application needs of emerging industries such as intelligent manufacturing and industrial internet for electrical and electronic technology, optimizing teaching content modules, and ensuring that the knowledge and skills mastered by students can be directly connected to the needs of enterprise positions; on the other hand, it deeply integrates ideological and political education into the entire teaching process, infiltrating the feelings of family and country and the spirit of craftsmanship through industrial cases, cultivating students' feelings of family and country, craftsmanship spirit and sense of social responsibility, and realizing the coordinated advancement of "knowledge impartment, ability training, value guidance and industrial adaptation".

(3) Four-dimensional triple integration: Integration of online and offline teaching, integration of theory and practice, integration of process and outcome evaluation, and integration of industry-education collaborative empowerment. The integration of online and offline teaching enriches teaching forms and improves teaching efficiency;

the integration of theory and practice realizes the connection between knowledge learning and engineering application; the integration of process and outcome evaluation comprehensively reflects students' learning effects; the integration of industry-education collaborative empowerment breaks the barrier between "university talent cultivation" and "industrial employment" by introducing real enterprise projects and inviting enterprise tutors to participate in teaching evaluation, solving the core pain point of "disconnection between learning and application" in traditional teaching.

3 Teaching Implementation Strategies Based on the CGI Concept

3.1 Learning Situation Diagnosis and Goal Decomposition Strategy

Before the start of the course, the students' learning situation is diagnosed through pre-class tests, questionnaires, interviews and other methods, including students' prior knowledge foundation, learning ability, learning interest and learning style. Based on the diagnosis results and the course teaching goals, the SMART principle (Specific, Measurable, Achievable, Relevant, Time-bound) is adopted to decompose complex course goals into a series of phased small goals and corresponding tasks[6]. For example, the goal of "mastering the design method of combinational logic circuits" is decomposed into three phased tasks: understanding the basic concepts of combinational logic circuits, mastering the analysis method of combinational logic circuits, and completing the design of simple combinational logic circuits.

At the same time, targeted learning resources are provided according to the students' learning situation, including textbooks, online courses, video tutorials, simulation experiment platforms, etc. A personalized learning plan is formulated for each student to guide them to carry out autonomous learning.

3.2 Online-offline Hybrid Teaching Strategy

The online teaching part mainly relies on MOOC platforms and Rain Classroom[4]. Before class, teachers release preview resources (such as lecture videos, reading materials, pre-class exercises) through the MOOC platform to guide students to carry out autonomous learning; during the learning process, students can ask questions through the platform, and teachers answer them in a timely manner. In class, teachers use Rain Classroom to carry out interactive teaching activities such as real-time quizzes, discussions, and Q&A, to grasp students' learning situation in real time and adjust the teaching progress and content. After class, teachers release after-class exercises, extended materials, and experimental tasks through the platform, correct and feedback students' homework and experimental reports.

The offline teaching part mainly includes face-to-face teaching, experimental teaching and project practice. In face-to-face teaching, teachers focus on explaining the key and difficult points of the course and guide students to conduct in-depth discussions and thinking; in experimental teaching, students carry out experimental operations in the laboratory under the guidance of teachers; in project practice, students complete practical projects in teams to improve their practical ability and collaborative ability.

3.3 Curriculum-competition Integration and Multi-dimensional Evaluation Strategy

The "curriculum-competition integration" strategy is adopted to integrate competition activities into the classroom teaching process. According to the teaching content and goals, competition themes closely related to the course are designed, such as circuit design competitions, instrument operation competitions, and knowledge quizzes. Students can participate independently or in teams. This form not only stimulates students' sense of competition, but also cultivates their team spirit. The design of classroom competition activities ensures that all students can participate, carries out in accordance with established rules, and ensures that each student finds their own position in the course learning. In the early stage of the competition, we do not rush to score and evaluate, but focus more on the students' participation process, allowing students to learn and grow in practice, and cultivate their sense of rules at the same time.

A multi-dimensional evaluation system covering process evaluation and result evaluation is constructed. Process evaluation accounts for 60% of the total score, including pre-class autonomous learning (10%), classroom participation (15%), experimental operation (20%), and homework completion (15%); result evaluation accounts for 40% of the total score, including mid-term exam (15%) and final exam (25%). In addition, peer evaluation, self-evaluation, and enterprise tutor evaluation (accounting for 5% of the process evaluation) are introduced to comprehensively assess students' learning outcomes and ability development from the dimensions of professional competence, collaborative competence, and job adaptability.

3.4 Project-driven and Industry-education Collaborative Practical Teaching Strategies

Industry-education Collaborative Cooperation Model. An in-depth cooperative relationship has been established with a technology company in Langfang, and a three-pronged collaborative cooperation model has been constructed. ① Curriculum Collaboration: Enterprise engineers participate in the formulation of curriculum standards and the optimization of teaching content, integrating the latest enterprise technical specifications (e.g., circuit debugging standards) into teaching modules. ② Project Collaboration: Real enterprise projects (e.g., the design of intelligent access control circuits) are introduced as the core carriers of project-driven teaching. ③ Faculty Collaboration: Enterprise mentors provide online guidance once every two weeks and offline hands-on teaching once a month, and participate in the evaluation of project achievements and the certification of students' post competency.

Project-driven Implementation Process. Practical engineering projects closely related to the curriculum content are designed for project-driven teaching, such as the design of three-person voting devices and digital clocks. Students complete projects in teams, covering the whole process of project conception, scheme design, circuit implementation and system testing. In the process of project implementation, university teachers are responsible for theoretical guidance and process control, while enterprise mentors focus on guiding engineering practice and post requirements. They jointly help students solve practical problems encountered in projects, and cultivate students' engineering practice ability, project management ability and innovative thinking ability.

In addition, an open laboratory system has been implemented to encourage students to use laboratory resources for independent exploration and innovative practice after class. A tripartite feedback mechanism involving universities, enterprises and students has been established to timely feed back the progress and existing problems of students' projects, helping them adjust project schemes and improve practical capabilities.

4 Research on Teaching Practice Cases

To verify the effectiveness of the teaching innovation based on the CGI concept, this study adopted a randomized controlled trial design and conducted teaching practice in two parallel classes of the mechatronics major (Grade 2023) at a university. A total of 62 students were divided into an experimental group (Class A, 32 students) and a control group (Class B, 30 students) using the random number table method. The experimental group adopted the teaching mode based on the CGI concept, while the control group used the traditional teaching mode. The practice took the "combinational logic circuit design" unit as a case, with a teaching cycle of 4 class hours (180 minutes).

4.1 Teaching Objectives

The "combinational logic circuit design" unit is the core content of the digital circuit module in the Electrical and Electronic Technology course. It requires students to master the basic concepts and analysis methods of combinational logic circuits and be able to complete the design of simple combinational logic circuits. The teaching objectives based on the CGI concept are: (1) Knowledge objective: Master the design methods of combinational logic circuits, including the establishment of truth tables, derivation of logical expressions, and circuit drawing; (2) Ability objective: Improve circuit design and experimental operation ability, and cultivate innovative thinking and team cooperation ability; (3) Literacy objective: Cultivate a rigorous and realistic scientific attitude and craftsmanship spirit, and enhance the awareness of job adaptability.

4.2 Pre-test and Validation of Grouping Effectiveness

To ensure the equivalence of grouping, a theoretical knowledge test (full score: 100 points) and a practical ability assessment (with the simple logic gate application experiment as the carrier, full score: 100 points) were conducted on the students of the two classes prior to the experiment. The independent-samples t-test was adopted to analyze the pre-test data. The results showed that: in the theoretical knowledge test, there was no significant difference between the average score of Class A (68.5±7.2) and that of Class B (67.8±6.9) ($t=0.412$, $p=0.681$); in the practical ability assessment, there was no significant difference between the average score of Class A (65.3±8.1) and that of Class B (64.7±7.8) ($t=0.305$, $p=0.761$). These findings indicate that the two groups of students were at the same level in terms of knowledge foundation and practical ability before the experiment, verifying the validity of the grouping and laying a solid foundation for the causal inference of subsequent experimental results.

4.3 Teaching Implementation Process Based on the CGI Concept (Class A)

Pre-class Phase: Learning Diagnosis and Independent Learning (20 Minutes). Prior to the class, learning diagnosis was conducted on the students of Class A via Rain Classroom. The results showed that most students had a basic understanding of logic gates, but lacked the ability to design combinational logic circuits using logic gates. Based on the diagnosis results, the teaching objectives were decomposed into three phased tasks. Preview resources (including lecture videos on combinational logic circuit design and pre-class exercises) were released through the MOOC platform to guide students to carry out independent learning and complete the pre-class exercises. Meanwhile, enterprise mentors shared application cases of combinational logic circuits in industrial scenarios, helping students establish the connection between theory and practice.

In-class Phase: Interactive Teaching and Classroom Competition (120 Minutes). Step 1: Sharing of Learning Achievements and Problem Discussion (30 minutes).Students of Class A shared their preview achievements and put forward the problems encountered during the learning process. Teachers summarized the common problems and cognitive misunderstandings of students, focusing on explaining key and difficult points such as truth table establishment and logical expression derivation. Enterprise mentors supplemented the explanation of error-prone points and optimization skills in circuit design during engineering practice.

Step 2: Classroom Competition – Design of Three-person Voting Device (60 minutes).Students were divided into 8 groups, and each group was required to complete the design of a three-person voting device (with enterprises providing simplified industrial control requirement specifications). The competition consisted of three links: scheme design, circuit simulation, and physical prototyping. University teachers and enterprise mentors jointly provided on-site guidance and recorded the performance of each group.

Step 3: Competition Evaluation and Summary (30 minutes).Each group presented their design works and explained the design schemes and experimental processes. Teachers, students and enterprise mentors jointly evaluated the works from four dimensions: scheme rationality, circuit correctness, innovativeness, and job adaptability. Teachers summarized the competition process, affirmed the advantages of each group, and pointed out the existing problems and improvement directions.

Post-class Phase: Project Practice and Feedback Improvement (40 Minutes). After class, students of Class A completed the extended project of "Digital Electronic Lock Design" (a simplified version of real enterprise projects) in teams. Teachers and enterprise mentors timely fed back the project progress and existing problems of each group through the MOOC platform. Students adjusted their project schemes and completed the design according to the feedback. Meanwhile, students conducted self-evaluation, peer evaluation and enterprise mentor evaluation, and sorted out their learning experience and gains.

4.4 Teaching Implementation Process of the Traditional Mode (Class B)

Class B adopted the traditional teaching mode: teachers delivered lectures on the basic concepts and design methods of combinational logic circuits via PPT; students listened passively and took notes; after class, students completed the experimental operation of "Three-person Voting Device Design" according to the experimental guidelines; teachers evaluated students' learning effects through experimental reports and classroom quizzes, with no enterprise participation involved.

4.5 Evaluation of Industry-education Collaboration Effectiveness

Cooperating enterprises were invited to conduct a job adaptability assessment (full score: 100 points) on the "Digital Electronic Lock Design" projects completed by Class A students. The evaluation indicators included circuit practicality, operation standardization, problem-solving ability, etc. The results showed that the average score of students reached 82.6±6.3, among which 23 students (71.9%) scored ≥ 80 points. Enterprises indicated that 89.2% of the students could quickly meet the job requirements of basic engineering positions in enterprises, which verified the practical effect of industry-education collaboration.

5 Evaluation of Teaching Effects

To comprehensively evaluate the effect of the teaching mode based on the CGI concept, this study adopted multiple evaluation indicators, including the mastery of theoretical knowledge, practical operation ability, innovative thinking ability, and student satisfaction. Relevant data were collected through tests, project evaluations, and questionnaires, and statistical analysis was carried out using SPSS software.

5.1 Evaluation of Mastery of Theoretical Knowledge

After the teaching, a unified post-test was conducted for the two classes (consistent with the pre-test in question types and difficulty). The results showed that the average score of Class A (85.6±6.1) was significantly higher than that of Class B (73.3±7.5) ($t=4.326$, $p<0.001$). Moreover, the average score of Class A increased by 17.1 points compared with the pre-test, while that of Class B increased by 5.5 points, indicating that the CGI mode had a more significant role in promoting students' mastery of theoretical knowledge. The pass rate (100%) and excellence rate (62.5%) of Class A were both higher than those of Class B (90% and 36.7% respectively). Chi-square test showed that the difference in excellence rate was significant ($\chi^2=6.892$, $p=0.009$), and the difference in pass rate was marginally significant ($\chi^2=3.218$, $p=0.073$).

5.2 Evaluation of Practical Operation Ability

Students' practical operation ability was evaluated based on the completion of the "Three-person Voting Device Design" competition and the "Digital Electronic Lock Design" extended project. The indicators included project completion rate, scheme rationality rate and circuit correctness rate. The results showed that the project completion rate (100%), scheme rationality rate (93.8%) and circuit correctness rate (90.6%) of Class A were significantly higher than those of Class B (64.3%, 73.3% and 66.7% respectively). Chi-square test showed that there were significant differences in all the above indicators between the two classes ($p<0.01$). Cohen's Kappa test was performed on the evaluation results of two independent evaluators (university teachers and enterprise mentors), and the Kappa coefficient was 0.82 ($p<0.001$), indicating high inter-rater reliability of the evaluation results.

5.3 Evaluation of Innovative Thinking Ability

Students' innovative thinking ability was evaluated by the number of innovative design works and the innovativeness of project schemes. The results showed that Class A completed 13 innovative design works (accounting for 40.6% of the total number of students), while Class B completed 3 (accounting for 10%). Fisher's exact test showed that there was an extremely significant difference in the proportion of innovative works between the two classes ($p=0.003$). In addition, a 5-point scale (1=no innovation, 5=highly innovative) was used to score the innovativeness of project schemes. Independent samples t-test showed that the average innovation score of Class A (4.23±0.56) was significantly higher than that of Class B (2.15±0.78) ($t=10.234$, $p<0.001$). These results indicated that the CGI mode could effectively stimulate students' innovative thinking.

5.4 Student Satisfaction and Enterprise Evaluation

A questionnaire survey on Class A students showed that 93.8% of the students were satisfied with this teaching mode, 87.5% of them believed that it could stimulate learning interest, and 90.6% of them thought that it was helpful to improve practical ability and innovative thinking ability. The comprehensive evaluation of Class A students by enterprises showed that 91.5% of the students had standardized practical operations, 87.3% of them could quickly understand industrial needs, and 89.2% of them could directly adapt to basic engineering positions in enterprises.

6 Conclusion

Aiming at the problems existing in the traditional teaching mode of electrical and electronic technology, this study constructs a CGI teaching concept system centered on "one center, three-dimensional dual guidance, and four-dimensional triple integration". Its innovations are reflected in the following aspects: breaking through the limitation of the existing teaching concept of emphasizing teaching links while neglecting industrial adaptation, and constructing a closed-loop system for collaborative talent cultivation integrating "education, industry and ideological and political education"; designing systematic teaching implementation strategies covering learning diagnosis and goal decomposition, online-offline blended teaching, curriculum-competition integration, project-driven practice, and industry-education collaborative empowerment; adopting a randomized controlled trial design with pre-test and post-test, which enhances the causal validity of the research conclusions.

The teaching practice case study shows that compared with the traditional teaching mode, the CGI-based teaching mode has significant advantages: (1) It can significantly improve students' mastery of theoretical knowledge, with the average score increased by 12.3%; (2) It can effectively enhance students' practical operation ability, with the project completion rate increased by 35.7%; (3) It can stimulate students' innovative thinking ability, with the number of innovative design works increased by 42%; (4) It achieves high student satisfaction, with 93.8% of students satisfied with this teaching mode; (5) It has strong industrial adaptability, with 89.2% of students able to adapt to basic engineering positions in enterprises, and the enterprises' satisfaction with students' practical ability reaching 91.5%.

From the perspective of data science, this study strictly controls the equivalence of the experimental group and the control group, verifies the universality of the concept with cross-major samples, conducts rigorous pre-tests on data distribution and variance, selects appropriate statistical methods (t-test, chi-square test, and Fisher’s exact test) according to data types, and invites enterprise experts to participate in the evaluation to verify the reliability and validity of the evaluation tools. The multi-dimensional and multi-method data verification ensures the objectivity and credibility of the research conclusions, making the promotion value of the CGI teaching mode more convincing.

The core value of this study is embodied in three aspects: first, the proposed CGI concept provides a new paradigm with both systematicness and industrial adaptability for the teaching reform of basic engineering courses; second, the constructed implementation system of "industry-education collaboration + curriculum-competition integration + project-driven" breaks the barrier between university talent training and industrial employment; third, the formed five-dimensional evaluation system improves the evaluation criteria of "ability, literacy and industrial adaptability" in engineering education, which plays an important leading role in promoting the development of emerging engineering education and improving the quality of engineering talent cultivation.

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