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Redesigning the Digital Logic Course under the Dual Orientation of Digital-Intelligence Empowerment and Value Guidance

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Abstract: In response to the major challenges confronting the Digital Logic course in the context of Emerging Engineering Education, including the disjunction between disciplinary instruction and value cultivation, the lack of authentic engineering contexts, and the overreliance on single-mode assessment, this study proposes a redesigned teaching model under the dual orientation of digital-intelligence empowerment and value guidance. Guided by the philosophy of outcome-based education (OBE), the study develops an integrated framework characterized by OBE orientation, value-based integration, and digital-intelligence support. At the level of course content, knowledge graph technology is employed to reorganize the underlying knowledge structure so as to promote the implicit integration of disciplinary knowledge with such value-oriented elements as craftsmanship, engineering ethics, and patriotic sentiments. At the pedagogical level, project-based learning is adopted, and an anti-hallucination artificial intelligence agent based on large language models is introduced as a cognitive scaffold to support blended inquiry-based learning. At the level of assessment, a whole-process, multidimensional evaluation system is established on the basis of multisource data collected from a smart teaching platform and an AI interaction backend. Teaching practice shows that the redesigned model has effectively enhanced students' innovative practical ability to solve complex engineering problems, while also strengthening their intrinsic motivation to contribute to national scientific and technological development. The study provides both a practical reform model and an empirical reference for the high-quality, intelligent development of foundational engineering courses.

Keywords: Digital Logic; Digital-intelligence empowerment; Value guidance; OBE; AI agent; PBL

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1. Introduction

Higher education is gradually moving away from traditional teaching practices and adopting more digital and intelligent approaches. Internationally, smart learning environments have attracted increasing attention and are regarded as an important direction for the future development of higher education. Such environments usually draw on context awareness, data analysis, and personalized feedback to improve teaching and learning [1,2].

In China, the National Education Work Conference held in January 2022 called for the implementation of the national strategy for educational digitalization. *The Key Tasks of the Ministry of Education in 2022* further stressed the need to respond to practical demands, deepen the use of digital technologies, encourage innovation, and improve the application of such digital technologies in education. These efforts were intended to drive the progress of educational digitalization and intelligent upgrading [3]. The 2023 World Digital Education Conference subsequently proposed a framework in which digital intelligence supports learning, teaching, governance, and research [4]. Digital-intelligence empowerment is thus not merely an international trend in educational technology. It has also become part of China's national strategy to improve the educational environment of universities and the quality of talent cultivation [5]. Meanwhile, fostering virtue through education remains a fundamental task of higher education. Disciplinary teaching and ideological and political education should work toward shared educational goals. *The Guidelines for Curriculum-Based Ideological and Political Education in Higher Education Institutions* stated that value cultivation, knowledge transmission, and ability development should be incorporated throughout disciplinary teaching [6,7].

Although the integration of digital technologies into classroom teaching has been attempted widely, the combination of digital-intelligent transformation and value education is still a daunting task in practice. An important problem is that the organic relationship between moral education and professional teaching materials is not strong. In most traditional classrooms, ideological and political aspects are artificially introduced or only superficially explicated, and they cannot integrate naturally with the interpretation and practice of the disciplinary knowledge. One more major obstacle is the skills of teachers in making good use of educational data. As stated in *Professional Standards of Teachers Digital Literacy*, most teachers are unable to convert diverse learning data into targeted, scientific teaching decisions [8]. Moreover, the traditional assessment systems overly focus on the end-of-term exam scores and fail to make good use of the plentiful process-based data produced by the learning processes. The imbalance in the structure is why it is hard to get an accurate and multi-dimensional assessment of student progress over time in professional knowledge, practical skills, and overall literacy.

The quick advancement of generative artificial intelligence, particularly large language models (LLMs), offers novel solutions to the stated teaching challenges. The available research has confirmed that LLM-based applications like ChatGPT can be used to help teachers create context-sensitive teaching cases, dynamically adapt personalized knowledge graphs, and guide students to analyze and address complex engineering questions [9–11]. Used in conjunction with knowledge graph systems, LLMs are able to successfully link conceptual understanding of theoretical knowledge in Digital Logic with practical ethics in engineering experience. The new mode of integration also enriches the diversified approaches of implementing curriculum ideology and politics into professional teaching [12,13].

In line with the construction of Emerging Engineering Education, the present research uses the Digital Logic course as the research object to investigate a realistic curriculum reform model which incorporates digital-intelligence empowerment and holistic-value development. According to the idea of outcome-based education (OBE), this study defines the curriculum purposes backward, based on desired learning results, i.e., the ability to master knowledge, engineering practice skills, and value literacy development.

The implementation of LLMs and virtual simulation technologies eliminates the conventional time and space constraints of physical classrooms. It combines online self-study and offline interactive instruction with intelligent tutoring delivered by AI agents. At the same time, the initial singular assessment pattern is fully optimized. A multi-dimensional assessment system is built as a data-driven solution that can be used to monitor and evaluate the ongoing learning activities of the students during the entire semester instead of basing the assessment only on the end-of-term examination results. With reference to the above teaching practice and exploration, this paper discusses the pragmatic solutions of value-oriented teaching empowerment via contemporary information technology in professional courses. It also offers practical and experiential evidence of the digital and intelligent transformation of other similar STEM courses.

2. Major problems of conventional Digital Logic instruction

Digital logic is among the fundamental hardware classes offered in computer-related fields of study, and it plays a crucial role as an interdisciplinary connection between discrete mathematics, advanced programming languages, and computer architecture. Apart from presenting introductory circuit theory, the subject should also develop a logical and systematic way of thinking in students as well as provide them with the necessary competencies to tackle difficult engineering tasks [14,15]. However, traditional teaching methods used in this field cannot meet modern demands due to the digitization of the educational system throughout the country and the increasing need to incorporate moral education into specific subjects. Three main constraints can be noted.

The first disadvantage of the situation is the lack of sufficient correlation between professional education and value development, limiting the overall educational role of the course. Digital Logic has rigorous concepts and much engineering practice. Nevertheless, the outdated educational systems focus on disciplinary knowledge and practical abilities but do not consider the aspect of value cultivation. Concepts on circuits are not often connected with the principles of craftsmanship, engineering ethics, or dialectics. So it's difficult to achieve a holistic level of professional competence and ethical literacy in these circumstances [16,17].

The second constraint is the present one-way knowledge delivery and the lack of real-life engineering problems, which hinder the creativity and teamwork abilities of students. The design of digital circuits has strong practicality. Teaching materials are separated from real project scenarios, so students will only remember the hypothetical equations but not be able to come up with working digital systems [18]. One more shortcoming is inadequate practical experience, so students cannot undertake open-ended and unstructured tasks, which are common in academic competitions. Besides, the traditional classroom does not take advantage of the most recent generative AI tools in education. Students require numerous testing, revisions, and circuit debugging on their complex system designs and do not have this kind of immediate, specific assistance. There is also no prompt support, which inhibits higher-order thinking and practical creativity among students.

The third issue is overreliance on summative assessment. Existing assessment methods do not meet the fundamental principles of OBE, and they are not able to demonstrate any change in the educational setting of the learners. The evaluation systems may influence the teaching structure and the behavior of the students during learning. Tests with a majority of standard questions have been demonstrated to measure memorized knowledge and pen-and-paper calculation abilities. These tests are unable to properly assess leadership, communication, and teamwork competencies when completing a group task under PBL and do not include all the learning records produced through the online teaching platform. Conventional evaluation criteria generally will not indicate how well students can utilize artificial intelligence tools, i.e., their capacity to write code, design circuits, and debug faults using LLMs and AI agents [19].

In short, traditional Digital Logic teaching faces three persistent challenges: insufficient attention to both professional education and value cultivation, a scarcity of authentic engineering projects for teaching organization, and slow progress in evaluation optimization. These challenges cannot be solved through partial adjustments and demand holistic curriculum restructuring. Digital and intelligent technologies provide solid technical support for such reforms. Project-based learning should serve as the core of teaching organization, and curriculum evaluation should adopt multi-dimensional objective evidence to assess students' comprehensive development.

3. Theoretical framework and operational mechanism for curriculum restructuring

This research is based on practical teaching experience and a general overview of the course, and it examines the relationships between the learning outcomes, teaching content, and instructional tools. It then creates a three-step plan to redesign courses: OBE orientation, value integration, and digital-intelligence empowerment. This strategy also builds a structure of implementation in the existing setting of blended learning.

3.1. Triple core logic guiding curriculum restructuring: OBE orientation, value integration, and digital-intelligence empowerment

Initially, OBE defines the overall direction of course redesign. The accreditation of engineering education focuses on student-centered pedagogy and desired learning outcomes [20,21]. Thus, the course planning must not be based on textbook sequences. Rather, it needs to start with determining the knowledge, skills, and values that students should acquire through the course. Teachers can carry out reverse teaching design based on expected learning outcomes, organize knowledge units, design suitable PBL tasks, and establish corresponding assessment standards.

Secondly, value-oriented teaching can shape students' professional identity and cultivate their sense of engineering responsibility. During the course restructuring phase, examples related to integrated circuits, the fabrication of chips, and other important areas are used in appropriate teaching units [22], which will enable students to realize the significance of Digital Logic and also to identify the relationship between what they learn and larger social and industrial requirements. In this way, students would be more actively involved in real engineering practice and consciously take on the responsibility of solving engineering problems.

Finally, digital-intelligence technologies can be applied to the optimized new teaching mode. PBL activities and the process-oriented assessment supported by OBE are difficult to implement properly if teachers only use traditional teacher-centered methods alone. This is why the course involves a combination of the Chaoxing platform, electronic design automation (EDA) simulation tools (e.g., Multisim), and AI agents. Each of these tools plays a different role in the teaching process. The Chaoxing platform is most often used to publish the learning tasks and document process-related information [23]. Meanwhile, AI agents provide real-time guidance for students' programming practice and circuit debugging after class. The adoption of the digital tools mentioned above can not only reduce a large amount of repetitive work for teachers, but also provide timely assistance to students with learning difficulties.

3.2. Overall structural design and operational mechanism of curriculum reform

Based on the aforementioned threefold core logic, **Figure 1** demonstrates the overall framework for the reconstruction of the Digital Logic course. It consists of three core layers: the foundational support layer, the instructional implementation layer, and the intended outcomes layer, together with a continuous improvement loop.

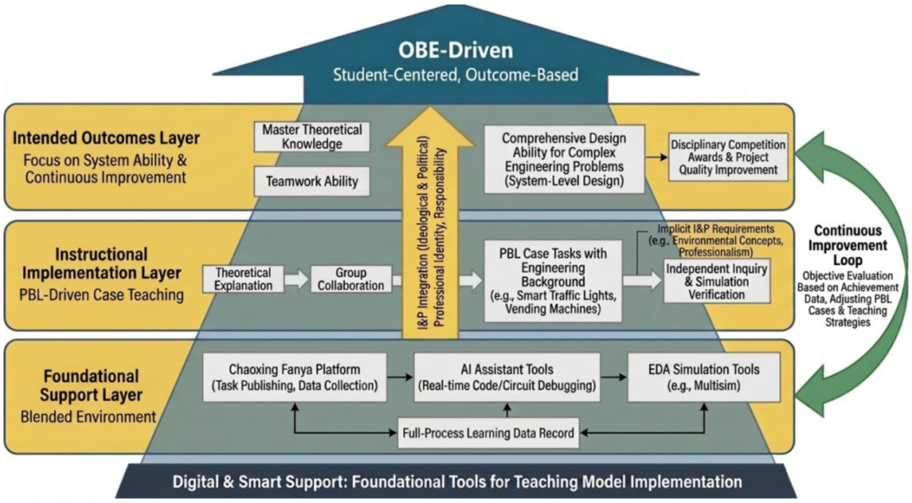

Figure 1. Overall structural design of the Digital Logic course

3.2.1. Foundational support layer: Building a blended online–offline environment

This dimension mainly covers the teaching platform and auxiliary tools adopted throughout the course. Before formal classroom teaching, teachers release micro-course videos, online quizzes, and PBL project implementation guidelines via the Chaoxing Fanya platform. Such pre-class resources allow students to complete personalized preview arrangements flexibly, rather than limiting all knowledge preparation to in-class teaching time.

Apart from conventional circuit simulation tools, this course integrates LLM-based intelligent agents to assist students in autonomous learning. During pre-class preparation and after-class practice, students often face difficulties in sequential circuit design and VHDL coding. They can describe specific technical problems to the AI agent and obtain targeted debugging guidance. The intelligent feedback will not substitute students' independent thinking and design judgment, but guide them in locating hidden errors and rethinking their design schemes [24,25]. All behavioral data generated from platform learning and AI tool interaction, including task completion status, quiz participation records, and tool application frequency, can be adopted as valid process assessment data to assess students' learning performance.

3.2.2. Instructional implementation layer: Organizing case-based learning through PBL

PBL is used to organize the main teaching activities. Once the necessary theoretical content has been covered, students work in groups on design tasks adapted from engineering applications. Typical projects include an intelligent traffic-light controller and the control logic for a simple vending machine. Each group is expected to search for relevant information, divide responsibilities among their members, develop a design scheme, and test the circuit with simulation software.

The moral value orientation is built into the specifics of the project instead of being presented as independent standalone content. As an example, a project outline can request that students take into consideration energy consumption when they compare different designs. Another task that can be given to students is to document procedures used in testing and give explanations on design decisions, whereby they engage in the rigorous and responsible work expected of electronic engineers. This combination of disciplinary knowledge with value cultivation is thus organic in the execution of particular engineering activities.

3.2.3. Intended outcomes layer: Developing system-level competence and continuous improvement

The revised course aims to assist students in gaining an understanding of the fundamental principles and techniques of digital logic and to acquire competencies that cannot be assessed solely through written examinations. These competencies cover teamwork, design communication, simulation-based validation, and the capacity to integrate various kinds of information in addressing complex engineering problems. Students' achievements in the electronic design and computer-related competitions can also indicate such outcomes. Indicators to look at would be the quality and completeness of the submitted projects and the results of the competitions. However, this kind of evidence should be taken alongside student performance in routine course-related activities.

The data on assessment is used to inform the next round of course planning. At the end of every term, the instructor reviews the results of online quizzes, presentations of PBL projects, project products, and final examination scores. The data will assist in determining how well individual objectives of the course were attained. If an indicator indicates that attainment is not satisfactory, the instructor locates teaching activities that can be linked to the indicator and modifies them for the next cohort. As an example, when students are struggling to complete a project, it could be broken down into more manageable steps, or further directions might be given to a knowledge unit connected with poor performance. It connects the findings of the assessments to particular changes in teaching and puts the OBE idea of continuous improvement into action.

4. Practical pathways for course redesign

The redesign is based on three interconnected aspects: course objectives and content, teaching methods and learning environment, and assessment.

4.1. Revision of course aims and content: Applying a knowledge graph to link discipline-based learning with value development

The course team starts by considering how the material in Digital Logic is structured. Knowledge graph technology is used to map important concepts and clarify the relations between them. The team can find connections that are not given much attention in the earlier content structure through this process, and consider the places wherein professional values, engineering ethics, and social responsibility can be properly integrated into the disciplinary topics. Instead of covering these elements in different blocks, teachers included them in explaining concepts, analyzing engineering cases, and discussing design decisions. Such a way is aimed at eliminating the rigid implantation of ideological and political content.

24 integration points of curriculum ideology and politics (one integration point per class) are identified. They are spread throughout various topics of the course based on the nature of teaching material. With such an organization, value cultivation is incorporated into the process of students' discipline reasoning and problem solving rather than serving as an independent teaching module. Examples of representative instances are given in **Table 1**.

Table 1. Integration of disciplinary knowledge and value-education elements

Knowledge topic	Value-education focus	Mode of integration	Expected outcomes
History of the Development of Digital Logic	Spirit of craftsmanship	Stories of scientists are incorporated when introducing the historical development of digital logic.	The spirit of craftsmanship
Number Systems and Coding Systems	Dialectics	The law of the unity of opposites is introduced through the binary notions of logic 0 and logic 1.	A dialectical-materialist worldview
Representations of Logic Functions	The multiplicity of interconnections	The five representational forms of logic functions are used to illustrate the multiplicity of interconnections emphasized in dialectical thinking.	The cultivation of innovative thinking
Logic Gate Circuits	The relationship between quantitative change and qualitative change	By showing how simple logic gates can be combined to build complex computers, students are guided to recognize the importance of cumulative learning.	A commitment to lifelong learning and a truth-seeking, pragmatic work ethic
Race Conditions and Hazards	Concrete analysis of concrete problems	The phenomena of race conditions and hazards in circuits are used to show that a given problem may admit multiple solutions and therefore requires context-specific analysis.	Openness to diverse approaches rather than rigid, one-dimensional thinking
Flip-Flops	Commitment to the nation and society	The state-retention property of flip-flops is used metaphorically to evoke the commitment of scientific and technological professionals to remember history and remain true to their original aspirations.	A commitment to serving the nation through science and technology
Monostable Multivibrators	Energy saving and carbon emission reduction	By utilizing the delay performance of monostable multivibrators to build automatic night-light circuits, teachers can effectively guide students to establish energy conservation concepts.	The awareness of reducing power consumption

For example, the traditional approach to teaching circuit simplification through Karnaugh maps will only list the criteria of grouping and the appropriate simplification techniques. This new course relates this theme to the trade-off between circuit economy and operational reliability. Students are thus taught to understand that simplifying circuits or reducing their costs must not affect the stability and safety of the system. In this manner, Karnaugh map teaching covers not only technical aspects but also the sense of judgment and responsibility in engineering design.

4.2. Redesigning teaching methods and the learning environment: PBL-based blended learning with AI support

When discussing the overall course organization, PBL is the principal framework used in blended learning. The course does not teach every knowledge point as a separate topic but instead incorporates similar concepts and methods into the projects that are adapted from practical engineering scenarios. Students gain and use the necessary knowledge during the process of requirements analysis, solution development, and design testing. AI agents are incorporated at suitable steps of the work to help retrieve the information, analyze the design, and debug it, but not to complete the projects on behalf of students. Representative PBL cases are presented in **Table 2**.

Table 2. Representative PBL cases of Digital Logic course

No.	PBL case	Core knowledge points
1	Multi-Switch Lighting Control Circuit	XOR/XNOR gates, combinational logic circuit design, truth tables, logic-expression simplification
2	Three-Person Voting Logic Circuit	Logic-function simplification, Karnaugh maps, AND–OR combinational circuits, the timing-independence of combinational logic
3	Sequential Control Circuit for an 8-Channel Running Light	Shift registers, clock pulses, sequential logic circuits, serial-to-parallel conversion
4	30-s Simple Timed Alarm Circuit	Asynchronous counters, frequency-division circuits, timing logic, decoding circuits, triggering mechanisms
5	BCD seven-segment digital tube decoding and display circuit	BCD coding, decoders, seven-segment display driving, code conversion
6	Simple DAC Circuit	Digital-analog conversion, weighted-resistor networks, digital-to-analog mapping, binary-weighted logic

As an illustration, there is one project that requires students to create a monitoring and alarm system for reservoir water levels. In teams, students begin by interpreting the requirements of the project and specifying the logic states related to various water-level intervals. They subsequently convert these requirements into truth tables along with state transition diagrams when sequential behavior is present. Once the logic design is finished, the circuit is constructed and tested in an EDA environment, and finally, the hardware prototype is created and validated. This exercise hence links requirement analysis, logic modeling, simulation, and physical implementation, which allows students to use theoretical information in various steps of an engineering design process [26].

In the context of individual learning support, more emphasis is placed on challenges that are encountered in circuit simulation and debugging. A course-specific AI agent using a large language model is created to offer students assistance in steps outside of class. Since a multi-purpose model can produce incorrect or irrelevant results for the course being taught, the course team creates a local knowledge base with common circuit examples, common errors, and other course materials. The retrieval of relevant information in this knowledge base to generate a response is performed by retrieval-augmented generation (RAG). The AI agent is intended to provide prompts rather than finish a design on behalf of students. Whenever a student enters a system requirement, it tends to react by asking questions that divide the problem into smaller steps, rather than instantaneously coming up with completed code or a full circuit diagram. To give an example in the water-level monitoring project, the agent could suggest to the student in this way: The sensor outputs should initially be depicted in binary signals. What circuit would be appropriate for this conversion? These types of questions focus students on what the next design choice is, but leave this analysis and implementation to the students themselves.

4.3. Redesigning assessment: A multisource approach covering the learning process

The combination of learning logs produced on the Chaoxing platform with interactive information provided by the AI tutoring system allows the collection of learning evidence during the entire learning cycle through the curriculum evaluation. This system incorporates formative and summative evaluation indicators and evaluates simultaneously how well students acquire theoretical knowledge, participate in PBL practice, and develop their engineering design capabilities. The general structure of this evaluation system is shown in **Figure 2**.

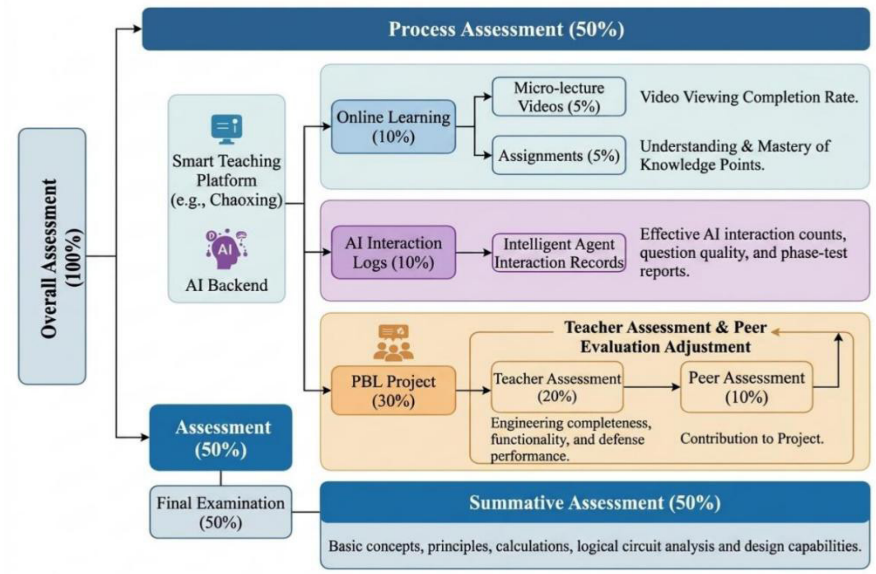

Figure 2. Multidimensional evaluation system

The practice of PBL projects is worth 30% of the entire course grade and involves the use of a hybrid assessment model that considers both group performance and individual contribution. The teacher assigns a base score to every team depending on their overall performance, which includes completion of system design, testing results, project folders, and defense presentations. Afterward, group members conduct mutual evaluation focusing on task fulfillment, technical output, and collaborative performance. On the basis of group baseline scores, peer feedback is adopted to adjust every member's final score. To avoid biased judgments caused by interpersonal factors, all peer ratings need to be cross-checked against project archives, work allocation records, and other participation materials. Such evaluation rules help differentiate individual contributions without undermining the collaborative attributes of group projects.

Different from the traditional evaluation mode dominated by a single final exam, the optimized system aggregates multi-dimensional evaluation outcomes derived from classroom participation, online learning behavior, project development, and the final exam. Such multi-source data can reflect students' progressive growth in knowledge application, engineering design, and collaborative ability in greater detail. From the curriculum perspective, teaching staff compare evaluation data from various tasks to summarize persistent learning obstacles encountered by students. Analysis of evaluation results provides empirical evidence for adjusting project requirements, learning resources, and in-class tutoring arrangements, thereby forming a benign cyclic mechanism linking student assessment and iterative teaching improvement.

5. Observed outcomes of course redesign

The redesigned model was applied to the Digital Logic course for two consecutive cohorts of computerrelated undergraduates at the university. Project performance, platform records, AI interaction logs, competition participation, and end-of-course surveys were adopted as evidence sources to reflect practical teaching changes in the implementation process. Since these findings were not obtained through strict experimental control, they should be regarded as preliminary results, rather than exclusive outcomes brought by the course redesign.

5.1. Development of engineering problem-solving and design skills

The modified practical exercises place greater emphasis on the development and testing of complete systems, instead of simply reproducing standard circuits provided in laboratory manuals. In PBL projects, students are required to analyze practical requirements, select appropriate components, formulate circuit schemes, and locate faults appearing in simulation and hardware tests. Compared with the previous verification-based teaching mode, project records and classroom observations show that students no longer rely entirely on fixed circuit diagrams, and they are more willing to propose independent design solutions and make corresponding revisions.

Within the two-year implementation cycle, college students showed higher learning engagement and obtained more awards in discipline competitions, including the National Undergraduate Electronic Design Contest and the Chinese Collegiate Computer Design Competition. Many participants mentioned that PBL training and AI-assisted debugging experience helped them sort out system modules and quickly locate errors under time-limited competition conditions.

5.2. Changes in learning engagement and perceptions of professional responsibility

After the completion of course restructuring, students' online learning behavior activity has increased by analyzing the data provided through the Chaoxing platform. The average weekly logins were 2 times the original value, and the video completion rate also significantly increased.

Records also reveal a shift in the types of questions raised by students. Early interactions tended to involve isolated concepts or procedural problems, whereas later questions focused on the decision-making aspects of design, including identifying and eliminating circuit hazards. Both of these trends reflect greater engagement with online resources and sustained attention to design-related issues.

Anonymous end-of-semester surveys offered supplementary information regarding students' understanding of the connection between technical learning and professional responsibility. In open-ended responses, students increasingly linked technical terms such as FPGA with themes including technological self-reliance, chip innovation, and bottom-line awareness. The responses indicate that many students began to consider the social, strategic, and safety dimensions of digital system design alongside its technical requirements. Although survey results cannot confirm stable value recognition, it can be concluded that students exhibited implicit thinking about value-related issues, and such thinking was connected to their understanding of professional knowledge.

5.3. Course-objective attainment and its use in course improvement

The quantitative method widely adopted in engineering education accreditation was applied to evaluate the attainment of course objectives. Data from examinations, assignments, laboratory work, PBL projects, and other assessment activities were matched with corresponding course objectives and aggregated using preset weights. The analysis covered three dimensions: mastery of basic principles, application of concepts in engineering practice, and awareness of professional accountability. Attainment values for all three objectives were higher than those recorded before the curriculum redesign. Nevertheless, without statistical testing and control of cohort effects, these results serve as descriptive evidence of improvement rather than proof of statistically significant causal effects.

Based on the OBE philosophy, the teaching team adopted the attainment matrix to identify objectives and knowledge domains where students achieved relatively poor performance. The team then analyzed detailed test results and project records to determine whether deficiencies stemmed from conceptual confusion, insufficient practice, or poorly designed tasks. Guided by these analytical findings, the team adjusted learning resources, classroom activities, project specifications, and assessment tasks for the subsequent teaching cycle. This analytical process acts as an important feedback source for curriculum revision, so that teaching adjustments can be formulated according to recurring trends in student performance.

6. Conclusion

With the ongoing technological revolution and the continuous improvement of engineering education accreditation requirements, curriculum optimization is essential for foundational hardware courses represented by Digital Logic. Guided by the OBE concept, this study realizes the smooth implicit integration of professional knowledge learning and value education in course teaching. By reconstructing the curriculum knowledge graph, adopting PBL and anti-hallucinatory AI agents to build inquiry-centered learning modes, the study also constructs a multi-dimensional whole-process evaluation system supported by multi-source learning data. Classroom evidence shows that the reform effectively enhanced students' innovative practical ability to solve complex engineering problems, while also strengthening their motivation to contribute to national scientific and technological development and reinforcing their sense of professional ethics.

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