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Reconstruction and Practice of Hierarchical Digital Logic Experiment System for Cultivating the Ability to Solve Complex Engineering Problems

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Abstract: This research aims to reorganize the digital logic experiment-based teaching framework on the premise of fostering the ability of students to solve complex engineering problems. The reform is driven by three deep-seated challenges: the large difference between the cognitive abilities of students, the rigidity of verification-only exercises, and the prohibitive cost of trial-and-error with purely physical experimentation. In the new four-module incremental arrangement of the verification-design-comprehensive layers, mechanical wiring of preset diagrams is replaced by having students face a real trade-off when they choose devices. A synergy between the virtual and the real is achieved through a virtual-real loop, i.e., simulation comes first, followed by hardware. Evaluation was redesigned in parallel. Based on the theory of the Zone of Proximal Development (ZPD) by Vygotsky, a three-level optional grading system was designed. It works in combination with a "preparation -operation-summary" trilogy rubric and directs the evaluative focus onto pre-class scheme planning and fault-isolation behavior during offline experimentation. The evaluation initiative is then shifted to the students themselves, who are thereby motivated intrinsically. Three years of teaching experience obtained at Lingnan Normal University confirms the effectiveness of the reform. The students moved beyond mechanical assembly and developed substantial skills in the field of system-level architecture design and multi-objective trade-off reasoning.

Keywords: Complex engineering problems; Digital logic experiment; Virtual-real synergy; Tiered differentiated evaluation; Zone of proximal development

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1. Introduction

1.1. Background and significance

There is an obvious change in the priorities of assessment in higher engineering education in China. Simple

information transfer is no longer considered enough, and developing students' ability to work with complex engineering problems has become the focus of attention [1]. There are two simultaneous forces behind this movement, which include the long-term development of Emerging Engineering Education and the rapid spread of accreditation criteria in engineering education. In the context of computer-based programs, Digital Logic has been used as a basic bridge between abstract algorithmic thinking and physical hardware implementation.

Problems that can be categorized as complex engineering tend to incorporate several technologies with strict physical limitations. Theoretical derivation by itself will not be able to create the competencies that these problems require. Experimental instruction is thus essential. It is necessary for students to travel through the entire practice cycle of requirement analysis, module selection, timing debugging, and fault isolation, with each step placed in real or extremely realistic engineering situations [2]. In such a case, what are the ways to redesign the framework of Digital Logic experimental teaching so that the learners have a systematic approach to hardware architecture and can learn how to innovate at the fundamental level of logic? This issue has turned into a priority in the sphere of computer education reform.

1.2. Limitations of current teaching models

Experimental instruction has a high strategic value that is widely recognized, but systematic practice still suffers due to differences in students' prior preparation as well as deep-seated pedagogical traditions. There are four deficiencies that clearly stand out.

To start with, heterogeneous cognitive backgrounds make uniform scheduling prone to polarization. Various recruitment channels create groups that are highly diverse in terms of their knowledge about simple physics experiments and information technology. The identification of the chip pins or complex circuit wiring is one of the tasks that may cause cognitive overload in under-prepared learners. In the case when a particular task arrangement is used by all students, there is a constant imbalance whereby high-performing students feel that the work is not challenging enough, whereas low-performing students fall further and further behind.

Second, verification-based content is stifling engineering creativity. Traditional experiments tend to be arranged in order to reflect textbook chapters. The students use lab manuals to perform a set of predetermined wiring operations, which can be better described as assembly work rather than logic-system design. The removal of logic design from real engineering situations will also diminish the internal desire to learn [3].

Third, excessive dependence on physical devices increases the trial-and-error expenses, and there is little time to do any logical design. Traditional education relies solely on the physical soundness of laboratory equipment. Low-level fault diagnosis (bad contact on breadboard, wrong wiring, etc.) may easily take more than the expected amount of time when operating at the system level. The students are thus given inadequate chances to deal with the problem of logic design and timing optimization, and it is almost impossible to compare alternative solutions meaningfully [4].

Additionally, even the summative assessment does not help to reflect the engineering thinking process. The most popular results-oriented framework, typically in the form of "attendance + final report," is easily undermined by plagiarism. But more importantly, it does not include the concepts of troubleshooting logic and iterative scheme reflection, which are among the most productive aspects of engineering practice. There is hence a big difference between existing assessment criteria and the aim of developing advanced engineering skills [5].

1.3. Reform ideas of this study

This research is based on the Outcome-Based Education (OBE) philosophy and uses backward design to redefine the experimental teaching system as a whole. The three interconnected strategies make up the main part of the reform.

The initial strategy is to create a three-level hierarchical experimental system — starting with verification, then design, and finally comprehensive innovation — using capability outcomes as the design focus. Various modules include tasks of different levels of difficulty. There is the option whereby students choose tasks on the basis of their level of preparation, thus achieving high learning autonomy, and the differences in educational background are naturally addressed.

The second plan is the modernization of the practical environment with virtual-real synergy. Multisim is incorporated in a closed-loop learning chain, whereby "pre-class virtual simulation trial and error" is followed by "in-class physical hardware debugging". The virtual environment allows the use of zero-cost trial and error, hence reducing extraneous cognitive load, and students shift focus from mechanical wiring to designing system-level logic architecture.

The third approach interlaces the ideological and political education (course ideology) with the all-round assessment of the process. To solve the difficult engineering issues, it requires more than just strong technical ability, but also engineering ethics. The ideological education is thus incorporated into the entire experimental process. Simultaneously, a differentiated rubric based on the three-step approach of preparation scheme, operation and debugging, reflection and summary allows assessment of students' engineering thinking and professional literacy in a comprehensive and dynamic way.

2. Restructuring the experimental teaching system oriented to complex engineering problems

Traditional digital logic experiments usually progress in line with the theory class timetable, dividing the experimental material to such an extent that it compromises the coherent formation of complex engineering problem-solving skills among students. Based on backward design under the OBE concept, this research breaks down the term "complex engineering problems" into four specific dimensions, which are logic modeling, scheme design, system debugging, and engineering specifications, which serve as guiding principles for restructuring experimental teaching in a coordinated manner in three interconnected aspects, namely, content framework, practical environment, and teaching organization.

2.1. Progressive reconstruction of experimental content: three levels and four modules

The inconsistency in the initial knowledge of students and the inflexibility of verification-only activities require a more dynamic content structure. Based on the concept of "Scaffolding Instruction," the current research rearranges experimental content into a three-step development that includes verification, design, and comprehensive innovation, with four particular modules as illustrated in **Figure 1** [6].

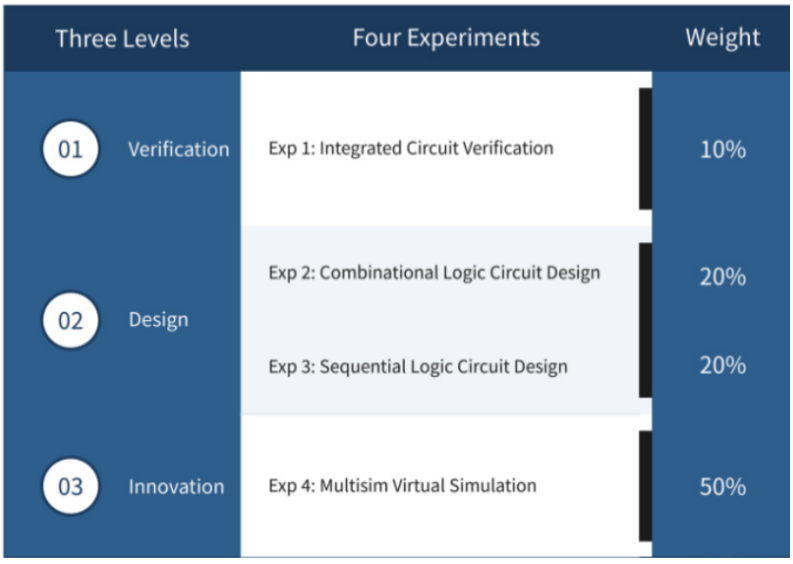


Figure 1. Experimental system of three levels and four modules

First Level: Verification Experiments (Foundation Building). At this level, students operate with basic devices, which include logic gates and flip-flops. Instead of mechanically wiring by diagram, they are asked to refer to the English datasheet of each chip in order to understand what the pins do and what the electrical limits are. The educational focus at this stage is clearly on engineering specifications and device cognition.

Second Level: Design Experiments (Enhancement). Being the main instrument of engineering thinking development, this level involves two large modules, which are combinational logic and sequential logic. The combinational logic module covers three-person voting circuits, parity checks, and blood transfusion detection, whereas running lights and multi-base counters are covered by the sequential logic module. There are no standard circuit diagrams. Students work on state machine extraction, Karnaugh map simplification, device selection, and joint debugging based on actual functional requirements. One unique demand at this point is a comparison between SSI and MSI implementations. Such comparison forces explicit trade-offs between cost, number of chips, and complexity of wiring among engineers, and confronts students with the non-uniqueness of solutions inherent to engineering problems of high complexity [7].

Third Level: Comprehensive Innovation Training (Challenge). The challenge tier includes a special Multisim simulation module that presents micro-projects based on real-world scenarios of application, including: water level monitoring; vending machine; traffic light control. To achieve success, students are required to pay attention to engineering aspects in full, including asynchronous reset, debouncing, boundary states, and other issues. This level of participation has extended cognitive development from “single-device cognition” to “complex system architecture design.”

2.2. Creation of a modern practical environment with “virtual-real synergy”

If experimentation is based exclusively on physical hardware, trial-and-error costs can be prohibitively high. Learners can use up significant cognitive resources trying to identify non-logical physical errors such as poor contact, floating pins, etc., which tend to lead to frustration instead of learning. Based on the complementary virtues of virtual and physical models, this paper has thus built a virtual-real synergy environment [8].

The pre-simulation platform is based on Multisim. During the design process and all stages of

development, the students are expected to follow a strict engineering discipline, i.e., to simulate before they work on the hardware. The software provides large component libraries, easy-to-use signal detectors, and most importantly, opportunities to experiment with trial and error at no cost. These affordances reduce extraneous cognitive load generated by mechanical processes and allow students to focus on the main logical design [9]. Hardware support is optimized for physical verification. In response to recurring problems faced when debugging offline, the teaching staff restructured the conventional experimental boxes by coming up with personalized matching modules and interfaces. The new board design significantly reduces chaotic cross-board wiring. In practice, it is much easier for students to follow the flow of signals. Virtual simulation of the logic and practical testing of the hardware properties are therefore a powerful synergy.

2.3. Blended teaching organization driven by cases and guided by course ideology

In its organizational setting, the traditional pattern of the teacher demonstrating what must be done first and then the student imitating it is replaced with a problem-oriented hybrid teaching approach enabled by the Chaoxing platform. MOOCs, micro-lectures, and recordings of simulation screens are provided in advance so that students with a poor background can load the required knowledge beforehand. Time spent in the classroom is thereafter used for focused interaction, such as teacher-student discussions, fault diagnosis, and scheme defense. As the students go through the comprehensive experiment, they engage in group work on practical problems, thus improving teamwork skills.

The integration of course ideology does not happen through mechanical indoctrination. A target system that closely matches the disciplinary nature of the course is defined and integrated into the teaching process without direct mention, as four values, one spirit, and two awarenesses are encapsulated implicitly, as seen in **Figure 2** [10]. When teachers discuss rules regarding grounding or floating pins, standard awareness and red-line thinking emerge by default. Race hazard debugging provides an atmosphere where students investigate point by point, which develops the craftsman spirit of striving towards perfection. The safety-focused projects, i.e., blood transfusion detection and water level monitoring projects, can be used as a fertile medium to implant the sense of engineering ethics, which is taking responsibility for human life. It is therefore ideological education that has been transformed into practical engineering behavioral norms that have a subtle impact but can be proven to work.



Figure 2. The ideological and political objectives of digital logic experiment

3. Tiered and differentiated evaluation mechanism focusing on process and capability

The summative assessment has been a part of digital logic experiments since the early days, e.g., attendance and final report. Since this model focuses on end results, students might be tempted to plagiarize wiring diagrams to obtain better grades. The most basic weakness is that the process of trial-and-error, debugging, and iteration (which one could arguably say is the most pedagogically important aspect of engineering practice) is completely inaccessible to the evaluators. Scores obtained in such a way do not represent students' achievement of complex engineering problem-solving skills [11]. To overcome this weakness, this paper devises a multidimensional assessment tool based on the OBE approach and principles of continuous quality improvement. It integrates two complementary mechanisms, namely: the difficulty-tiered optional grading scheme and the three-step experimental process rubric.

3.1. Tiered differentiated grading mechanism based on difficulty gradients

The implementation of a single grading standard for students who have diverse backgrounds of preparation will lead to anticipated issues: the weak students become frustrated; the strong students are not challenged enough. The idea behind an alternative approach is based on the theory of the Zone of Proximal Development (ZPD) introduced by Vygotsky. In turn, this research presents a staged and optional grading system as part of the design and comprehensive innovation modules, which are structured as shown in **Table 1**.

Table 1. Tiered differentiated grading mechanism

Experiment / Total	Compulsory / Points	Optional / Points
Integrated Circuit Function Verification /100	Gate Circuit Function Test /40	D Flip-Flop Function Test; /50 JK Flip-Flop Function Test; /60
Combinational Logic Circuit Design /100	SSI-based Three-Person Voting Circuit /40	MSI-based Parity Check Circuit; /50 MSI-based Blood Transfusion Compatibility Circuit; /60
Sequential Logic Circuit Design /100	Four-Channel Running Light Circuit /40	Modulo-M Counter (M<16); /50 Modulo-M Counter (256>M>10); /60
Multisim Virtual Simulation /100	Water Level Monitoring System /40	Vending Machine System; /50 Traffic Light Control System; /60

In this system, any standard 100-point module is divided into two major assessment areas, which are: Mandatory (Basic) and Optional (Challenge). The compulsory module can score 40 points. Competence standards at the basic level are used in this area. Each student performs assigned tasks, including the four-channel running lights and three-person voting circuit based on SSI, so that every student achieves the lowest level of engineering cognition as required by the syllabus. The optional module can score 50/60 points. This is where differentiation of higher-order thinking is developed. Students declare their choice of parallel tasks, which are set at two levels of difficulty. To illustrate, in the Multisim comprehensive simulation, a student initially assesses his or her own foundations before deciding between moderately difficult (vending machine, 50 points) or more demanding (traffic light control system, 60 points), depending on the severity of the timing constraints that apply to each.

The most important aspect of this mechanism is the restoration of evaluative decision-making power to students. Studies in educational psychology indicate that cognitive intrinsic motivation is highest when task difficulty is matched to individual ability, and learners have the freedom to select [12]. The operational evidence shows that there are two complementary effects: the less prepared groups experience a reduction in

their academic anxiety, whereas the high-performing students experience a score-based leverage effect that ignites their intellectual curiosity. A tiered improvement in one classroom can therefore be attained.

3.2. Implementation of full-process evaluation via an "experimental trilogy"

The solution of a complex engineering problem is inherently non-linear and iterative, as it involves the stages of modeling, simulation, implementation, debugging, as well as optimization. The capability performance at every sub-stage needs fine-grained measurement. The course consequently adopts an assessment of the three-step process based on the model of preparation, operation, and summary.

Step 1: "Preparation" evaluation emphasizing scheme design (30% weight). The mechanical ritual of copying the lab manual is eliminated. Preparation is redefined as preliminary engineering scheme design. Before stepping into the physical laboratory, each student writes out logic deduction proposals. The evaluative focus at this stage is on the rationality of the schemes and the cost-effectiveness of the chosen components, which creates a habit of planning in a systemic way expressed as thinking before acting.

Step 2: "Operation" evaluation focusing on fault isolation (40% weight). In offline hardware sessions, it is no longer enough to merely determine whether the LED lights up or not. The focus now moves to dynamic observation of student debugging behavior. Physical anomalies are used by instructors to assign a specific rubric to assess whether students have mastered how to use multimeters and oscilloscopes in order to find fault nodes when race hazards, clock glitches, or floating pins occur. This evaluative mechanism, based on hands-on trial and error, pushes students to understand the low-level physical characteristics better [13].

Step 3: "Summary" evaluation highlighting critical reflection (30% weight). The engineering report has been reoriented: instead of being a mechanical summary of experimental data, it serves as the main source of information in engineering communication. The students need to examine the experimental data thoroughly, identify the sources of circuit failures, and explain the differences between the measured outcomes and the results of virtual simulation. This post-stage evaluation is well suited to measure the ability of each student to cross the theory-practice gap because it relies on critical thinking as its evaluative center [14].

The combination of tiered and differentiated optional grading with full-process evaluation allows the assessment framework to demonstrate the entire lifecycle of engineering problem solving. The scores of students stop relying merely on whether the circuit can be made functional at last; scheme reasoning quality, rigor in the debugging approach, and depth of reflective analysis all play an important role in the overall grade.

4. Effectiveness and analysis of teaching innovation practices

The revamped tiered experimental teaching system in the subject of Digital Logic (based on the philosophy of OBE and virtual-real synergy) has been implemented as an official program within the computer-related courses offered by Lingnan Normal University, including the specializations in Artificial Intelligence and Big Data. This system has undergone almost three years of continued improvement. Assessment of effectiveness was carried out in three evaluative dimensions, namely cognitive development, emotional involvement, and the teaching-research environment. The empirical basis behind this evaluation consists of behavioral traces registered through the Chaoxing platform, records of process evaluation made using structured rubrics, and collected teaching-research products.

4.1. Cognitive advancement: Marked elevation in complex engineering problem-solving competencies

Essentially, engineering capability development is about the deconstruction and reconstruction of cognitive architectures working within several simultaneous physical constraints [15–16]. Through the synergy between the tiers of the experimental structure and the leveled differentiated assessment rubrics, it was observed that students were showing a significant trend in the direction of higher-order cognitive processes, namely analysis, evaluation, and creation according to the revised taxonomy proposed by Bloom. Longitudinal operational data show that, over time, more and more students opt into the most difficult optional module when faced with the stepped task architecture of mandatory baseline + optional challenge. The traffic light control system, which includes many timing restrictions and asynchronous control logic, is a good example of such challenging choices.

A similarly fundamental change in the behavioral repertoire of students was observed in the context of hardware anomalies as they took offline hands-on tests. Initial generations of students typically showed signs of "blind rewiring and extreme reliance on instructor intervention." The "block isolation method," however, became a default diagnostic strategy as the reformed system matured and students began to instinctively grab multimeters or oscilloscopes to perform systematic logic-level troubleshooting. This shift in behavior, which has occurred between mechanical assembly under schematic reproduction and requirement-driven system-level architectural design, provides strong proof of significant increases in hardware architecture reasoning, fault isolation methodology, and comparison of multi-objective schemes in poorly structured complex engineering situations.

4.2. Intrinsic drive awakening: deep fusion of learning motivation and engineering literacy

The task of motivating students intrinsically is an end that goes beyond the superficial learning of skills; it is a core expectation of the pedagogical model reconstruction. Convergent data obtained via multidimensional questionnaire surveys conducted on the platform, complemented with systematic text mining of experimental reflection logs, revealed three significant advances in students' engineering experience.

First, it is evident that virtual-real synergy decreases trial-and-error anxiety. More than 85 percent of the students surveyed stated that the Multisim-based virtual pre-stage significantly reduced the helplessness they had felt before encountering unfamiliar physical hardware without having practiced it beforehand. Through the process of institutionalizing zero-cost trial-and-error, this mechanism essentially restored the psychological safety of students, encouraging them to experiment with more unconventional logic structures with much more confidence and creative freedom.

Then, case-driven tasks triggered a reorganization of professional identity. The insertion of abstract logic gate processes into physical engineering contexts that are actually real-world applications, such as water level monitoring systems or vending machine controllers, was an effective way of bridging the conceptual gap between theory and application. The presence of high-frequency interactive behaviors and the continuous increase in the amount of self-directed resource exploration information stored on the Chaoxing platform both confirm the existence of a bidirectional activation loop between classroom participation intensity and professional identity consolidation [17].

Thirdly, ideological education was embedded implicitly rather than delivered through didactic lectures. The qualitative analysis of reflection logs showed repetitive thematic expressions, including: (i) the causal

link between signal integrity and wiring specification compliance; (ii) collaborative fault diagnosis in team settings; (iii) perseverance in seeking underlying logical consistency in debugging. The fact that the aforementioned motifs recur verifies that the preset ideological structure, i.e., the four values, one spirit, and two awarenesses, has gone beyond the formulaic indoctrination. It has been transformed into a real part of the engineering behavioral values and professional ethical pledges that are voluntarily observed by the students in practice [18].

4.3. Ecological reshaping: A virtuous closed loop linking teaching-research co-evolution and continuous improvement

When the reform of the experimental system had gone beyond the superficial changes into the deep structures of the organization, it triggered at the same time a holistic change in the research capacity of the teaching team. The result is that there has been an organic development of a very active community of practice [19]. In the area of resource construction, the team developed a three-dimensional pedagogical framework in which micro-lecture clusters, multi-level laboratory manuals, virtual engineering case repositories, and standardized assessment rubrics were systematically integrated. Taken together, such resources provide solid operational support to the routine delivery of blended instruction.

In respect of professional development of the faculty, the team implemented a systematic developmental system that was defined as a way of nourishing teaching with reform and promoting improvement using data. The team members had several breakthroughs in the teaching reform programs at the provincial level, in excellent academic papers, and in teaching innovation competitions. There was an ongoing quality improvement (CQI) cycle that would follow the path of practice reflection, research, and re-practice and hence was crystallized incrementally. This self-repetitive closed loop not only ensures the high transferability and reusability of the reconstructed scheme but also builds up the core faculty's intellectual capital that is necessary to upgrade the whole computer hardware course cluster foundationally oriented towards engineering [20].

5. Conclusion

In response to the need to develop competencies to solve complex engineering problems in the general context of Emerging Engineering Education, this paper has designed, piloted, and incrementally improved a series of deep-structural reform interventions based on the philosophy of OBE. This reform also addresses some of the deeply entrenched shortcomings in traditional experimental teaching of "Digital Logic," such as the immutability of verification-only materials, the one-dimensional nature of assessment tools, and the long-lasting inadequacy of higher-order engineering reasoning training. The reform has made it possible to achieve a qualitative cognitive shift in students, namely, from the mechanical assembly of hardware to systematic engineering thinking. At the same time, an auto-reinforcing virtuous circle of co-evolution between teaching and research has been established in the course team, creating a steady stream of intellectual energy. These interconnected mechanisms have enabled the shared educational goals of developing a genuine identity as a professional and an intrinsic sense of engineering ethics to be achieved demonstrably.

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Disclosure statement

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References

[1] Dan Z, Samuel M, Tan SY, 2025, Emerging Engineering Education in China. International Journal of Engineering Pedagogy (iJEP), 15(2): 153–164. https://doi.org/10.3991/ijep.v15i2.53627

[2] Seguí Gil, Lucía G, Martínez M, 2023, The Challenge of Developing and Assessing Transversal Competences in Higher Education Engineering Courses. RiuNet (Politechnical University of Valencia), 39(1): 2–13.

[3] Costley C, 2007, Assessment and Evaluation in Higher Education. Investigación, 83(6): 157–170. https://doi.org/10.1016/j.quascirev.2013.10.026

[4] Angulo I, Garcia-Zubia J, Orduna P, et al., 2019, Integral Remote Laboratory for Programmable Logic. IEEE. https://doi.org/10.1109/expat.2019.8876561

[5] Qadir J, Taha AEM, Yau KLA, et al., 2020, Leveraging the Force of Formative Assessment & Feedback for Effective Engineering Education. https://doi.org/10.35542/osf.io/a4d5q

[6] Hanley D, 2020, Initial Implementation of Active Learning Strategies in Large, Lecture STEM Courses: Lessons Learned from a Multi-Institutional, Interdisciplinary STEM Faculty Development Program. International Journal of STEM Education, 2020(7): 1. https://doi.org/10.1186/s40594-020-0203-2

[7] Jiménez-Hernández EM, Oktaba H, Díaz-Barriga F, et al., 2020, Using Web-based Gamified Software to Learn Boolean Algebra Simplification in a Blended Learning Setting. Computer Applications in Engineering Education, 2020(28): 1591–1611. https://doi.org/10.1002/cae.22335

[8] Yan FG, Ji XY, Lian H, 2024, Research on the Design and Model of Ideological and Political Teaching of the "Digital Circuit and Logic Design" Course. SHS Web of Conferences, 2024, 187: 01019. https://doi.org/10.1051/shsconf/202418701019

[9] Foss M, Liu Y, 2021, Creating Solutions through Project-based and Experiential Learning: A Case Study of the Concept Center. The International Journal of Engineering Education, 37(6): 1630–1642.

[10] Guo WJ, Yang ZM, 2024, Teaching Reform and Exploration of Digital Logic Course under the Background of Emerging Engineering Education. Industry and Information Technology Education, 2024(1): 58–62.

[11] Tai J, Ajjawi R, Boud D, et al., 2018, Developing Evaluative Judgement: Enabling Students to Make Decisions about the Quality of Work. Higher Education,76(3): 467–481. https://doi.org/10.1007/s10734-017-0220-3

[12] Salehi S, Burkholder E, Lepage G P, et al., 2019, Demographic Gaps or Preparation Gaps?: The Large Impact of Incoming Preparation on Performance of Students in Introductory Physics. Physical Review Physics Education Research, 2019(15): 2. https://doi.org/10.1103/PhysRevPhysEducRes.15.020114

[13] Maskos K, Schulz A, Oeksuez SS, et al., 2025, Formative Assessment in Mathematics Education: A Systematic Review. ZDM — Mathematics Education, 57(4): 679–693.

[14] Liu H, Zhu Y, 2020, Research on the Construction of Teaching Quality Evaluation System. Journal of Physics Conference Series, 2020(1673): 012055. https://doi.org/10.1088/1742-6596/1673/1/012055

[15] Tsoi YM, Anzovino EM, Erickson HA, et al., 2019, Variations in Implementation of Specifications Grading in STEM Courses. Georgia Journal of Science, 2019(77): 2.

[16] Chen J, Kolmos A, Du X, 2021, Forms of Implementation and Challenges of PBL in Engineering Education: A Review of Literature. European Journal of Engineering Education, 46(1): 90–115. https://doi.org/10.1080/03043797.2020.1718615

[17] Radhamani R, Kumar D, Nizar N, et al., 2021, What Virtual Laboratory Usage Tells us about Laboratory Skill Education Pre-and post-COVID-19: Focus on Usage, Behavior, Intention and Adoption. Education and Information Technologies, 26(6): 7477–7495. https://doi.org/10.1007/s10639-021-10583-3

[18] Bairaktarova D, Woodcock A, 2017, Engineering Student's Ethical Awareness and Behavior: A New Motivational Model. Science and Engineering Ethics, 2017(23): 1129–1157. https://doi.org/10.1007/s11948-016-9814-x

[19] Smeplass E, 2025, Nurturing Inclusivity and Professional Growth among Vocational Teachers through Communities of Practice. Pedagogy, Culture & Society, 33(3): 785–804. https://doi.org/10.1080/14681366.2023.2268108

[20] Walls C, 2024, Enhancing Construction Management Education Through Collaborative Learning. Creative Education, 15(9): 1982–1990. https://doi.org/10.4236/ce.2024.159121

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