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Exploring an experiential learning project:A case study through Kolb's Learning Theory

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Exploring an experiential learning project: A case study through Kolb's Learning Theory

Abstract: China has advanced the reform plan of "Emerging Engineering Education" since 2017. 1457 teaching reform projects involving over 300 universities under the "Emerging Engineering Education" initiative have been approved. In this context, the University of the Chinese Academy of Sciences (UCAS) has actively participated in engineering education reform based on experiential learning model. This study investigates the impact of experiential learning programs on the development of practical higher-order cognitive skills among full-stack talents in chip design and manufacturing. Based on the learning circle theory, we adopt an exploratory single-case research method. We interviewed 5 students who participated in the "One Student, One Chip" project initiative by the UCAS, and organized the data collected from multiple sources through the coding process of "open coding, axial coding and selective coding". We explore and propose the 2 new concepts "experiential learning spiral" and "practical higher order cognitive skills". It is found that experiential learning is a spiral progression process, higher-order cognitive skills are practice-oriented, and in different learning cycles, different concrete experiences and active experimentation affect the formation of different skills of engineering students in the direction of chip design and manufacturing.

Key Words: kolb's learning theory; experiential learning spiral model; practical higher-order cognitive skills

INTRODUCTION

Engineers, entrusted by the public, are required to apply their professional knowledge and skills to engage in practice, design, and innovation, thereby creating engineering solutions to address societal needs [1]. They participate in the application, operation, design, and development of projects and must possess higher-order cognitive skills, such as analysis, evaluation, and creativity [2], [3], [4], [5]. However, current educational models in engineering education have limited effectiveness in cultivating these skills among students. This limitation stems from an emphasis on knowledge comprehension over application in educational philosophies [6], and theoretical courses that are disconnected from real-world engineering experiences [7].

To address this, engineering education institutions worldwide are actively promoting reforms based on experiential learning. A notable example is the New Engineering Education Transformation (NEET) initiative at the Massachusetts Institute of Technology (MIT), which implements a cross-departmental, project-centered systemic reform. This initiative empowers engineers for the new era through career-oriented experiential education [8].For a three-year project-based learning experience, undergraduate students are selected from four programs: Autonomous Machines, Climate and Sustainability Systems, Digital Cities, and Living Machines. During this period, they work autonomously on the design and implementation of real engineering projects [9]. Similarly, University College London (UCL) has implemented the Integrated Engineering Programme (IEP) across eight departments. Centered on problem-based learning, the program designs a series of project-based courses that enable students to independently engage in engineering practices through progressive real-world project experiences, fostering the development of higher-order cognitive skills [10].

In China, with the ongoing advancement of the government's "Emerging Engineering Education" reform, many universities are actively promoting experiential learning-based educational reforms. For example, the Southern University of Science and Technology established the School of System Design and Intelligent Manufacturing in 2018, creating a talent cultivation model that integrates "knowledge transmission and capability development through multidisciplinary collaboration" across the curriculum. This is achieved through a progressive project-based teaching approach, enabling students to autonomously construct knowledge and enhance their skills during experiential project practice [11]. Similarly, the Future Technology Institute at Beihang University has transformed traditional lecture-based courses by systematizing previously fragmented structures. Adopting a problem-based and theory-practice integrated teaching approach, the institute has developed a series of courses characterized by their applicability, comprehensiveness, and experiential nature [12]. In summary, cultivating higher-order cognitive skills through experiential learning has become a focal direction in engineering education reform.

Chip design and manufacturing is a systematic engineering process involving a complete workflow across the entire chain of "design-manufacturing-packaging-testing." This field requires the cultivation of full-stack talents who possess both theoretical design thinking and practical manufacturing skills [13]. From the perspective of students' autonomous learning experiences, a "student-centered" instructional design that integrates theoretical courses with industrial practices has become a consensus among engineering education researchers. This approach aims to cultivate professionals in chip design and manufacturing who possess systemic thinking abilities and the skill to solve complex engineering problems [14], [15], [16]. However, China is experiencing a shortage of experts with complete knowledge in the full chip design and manufacturing process, as well as skill in processor chip architectural design, due to the domestic processor chip industry environment and university talent cultivation methodologies. According to the "Manufacturing Talent Development Planning Guide" jointly released by the Ministry of Education of the People's Republic of China, the talent gap in the new-generation information technology industry, represented by the chip industry, is projected to reach 9.5 million by 2025 [17].In August 2019, the University of Chinese Academy of Sciences (UCAS) launched the "One Student, One Chip" open-source processor chip teaching and physical practice project. The curriculum, which is based on experiential learning and is designed around the complete chip design workflow, stresses both theory and practice, with the goal of developing full-stack chip talents that are proficient in both chip design thinking and manufacturing.

This study adopts an exploratory case study approach, using Kolb's "Learning Cycle Theory" as the foundational analytical framework and the "One Student, One Chip" experiential learning project at UCAS as the case sample. It comprehensively analyzes the influence mechanism of spiral experiential learning on the higher-order cognitive skills of full-stack talents in the chip domain. The research question focuses on how experiential learning programs influence the development of practical higher-order cognitive skills among full-stack talents in the chip field.

LITERATURE REVIEW

Engineering Education and Experiential Learning

The concepts of experiential learning and experiential education are often used interchangeably [18]. However, experiential learning emphasizes the active role of students to a greater extent, to the point where the teacher may not be a necessary participant. It can be defined as “individual transformation resulting from reflection on direct experiences, leading to the development of new abstract and applied skills in the learner” [19]. In 1984, based on the learning theories of John Dewey, Kurt Lewin, and Jean Piaget, Kolb proposed a four-stage experiential learning cycle model (Figure 1): “concrete experience, reflective observation, abstract conceptualization, and active experimentation.” This model clarified the fundamental process of experiential learning [20]. Kolb categorized these four stages into two fundamental dimensions: the comprehension dimension and the transformation dimension. Concrete experience and abstract conceptualization belong to the comprehension dimension, while reflective observation and active experimentation belong to the transformation dimension [21]. Concrete experience entails gaining knowledge via direct observation, while abstract conceptualization centers on understanding knowledge by conceptual interpretation and symbolic representation. It highlights the development of subjective conceptual models and evaluative judgment. [22]. Reflective observation focuses on conceptual content, achieving intentional transformation through internal reflection, while active experimentation targets the real world, representing an expansive transformation through through the active manipulation of the external environment..

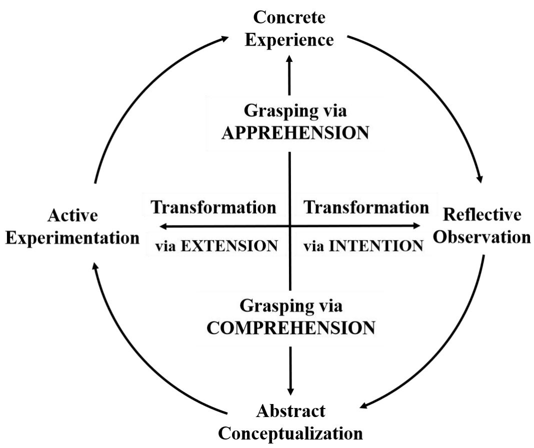

Figure1. Experiential Learning cycle Model

In recent years, research on integrating experiential learning into engineering education has gained increasing attention, and practices based on the experiential learning cycle theory have become more widespread. On one hand, researchers focus on the micro-level, examining the internal processes of experiential learning and conducting studies on engineering curriculum design reforms. Engineering education institutions worldwide have incorporated experiential learning into various course designs.

Through this institutionalized approach, students engage in continuous reflection and conceptualization during experiential activities, achieving a deeper understanding of theoretical knowledge. Simultaneously, real-world engineering practices enhance their application and creative skills [23], [24], [25]. This creates a cyclical model of experiential learning where theory and practice mutually reinforce and integrate. On the other hand, researchers focus on the macro-level, exploring the establishment of educational models based on the learning cycle theory. Some scholars use the experiential learning cycle as a theoretical foundation, combining it with specific practical reforms to build educational models. These models are validated through quantitative analysis and testing, demonstrating their effectiveness in talent cultivation [26], [27].

Full-stack talent development in the chip field falls within the scope of engineering education. Although research on such talent development is limited, there is a consensus on the importance of experiential learning. One approach involves shifting the focus of education to a student-centered model. This integrates technical research, development, and engineering practices into a learning platform where students “learn by doing” and “do by learning”. This enables students to independently synthesize and integrate interdisciplinary knowledge at a deeper level [28], [29]. Another approach involves adopting project-based teaching methods. By using the life cycle of integrated circuit (IC) products—design, manufacturing, packaging, and testing-as a framework, students engage in real-world chip design or manufacturing projects. They combine theoretical learning, scientific research, and engineering practice within a structured project theme, standardized design criteria, and limited budgets. Through iterative development processes that blend real engineering experiences with abstract theoretical thinking, students achieve significant skill enhancement [30], [31], [32].

Experiential Learning and Higher-Order Cognitive Skills

The renowned American educator Bloom proposed the Taxonomy of Educational Objectives, which categorizes cognitive domain objectives into three progressive stages: the knowledge domain, the affective domain, and the psychomotor domain [33]. In 2001, Anderson, a student of Bloom, refined the original taxonomy, revising the cognitive process dimension into six hierarchical levels: remembering, understanding, applying, analyzing, evaluating, and creating (Figure 2). Higher-order cognitive skills includes analyzing, evaluating, and creating. Analytical skills refers to students’ capacity to analyze, compare, summarize, and generalize what they have learned. Evaluation skills involves making value judgments based on intrinsic or extrinsic criteria, requiring critical thinking and judgment skills. Creative skills refers to generating new ideas, approaches, and thinking [34].

Engineering education researchers have long focused on cultivating higher-order cognitive skills in engineering students and have explored the role of experiential learning in this process. Studies show that integrating experiential learning into the engineering design process enhances students’ skills to construct knowledge and develop innovative solutions to complex problems [35], [36]. Additionally, experiential learning courses provide students with real-world experiences necessary for creative production, improving their vocational competence and metacognitive understanding of engineering knowledge [37],

[38]. Furthermore, experiential learning enables learners to reflect on and critically evaluate the relationship between theory and practice, facilitating the effective application of theoretical knowledge [39], [40].

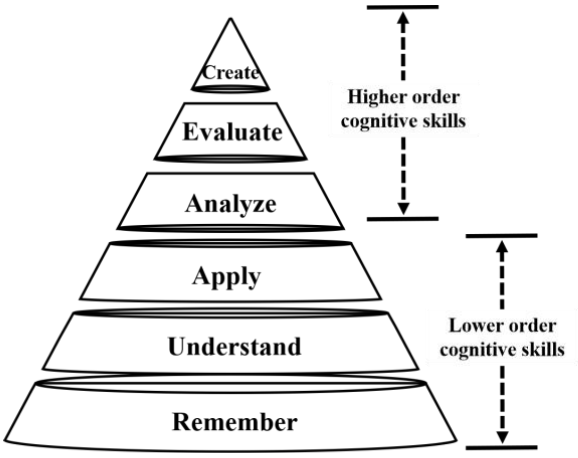

Figure2. Bloom's Taxonomy

Based on the above review, we find that experiential learning has been systematically applied in engineering education, and its positive impact on the development of higher-order cognitive skills among engineering students has been widely confirmed. However, some research gaps remain. First, while existing studies emphasize experiential learning elements such as autonomous experience, authentic project experience, and project application practice for cultivating talents in chip design and manufacturing, no research has systematically analyzed these elements within an experiential learning framework. Second, current studies on the cultivation of higher-order cognitive skills in engineering students often focus on theoretical thinking development, lacking integration with real-world practices. As a result, the proposed skill development pathways are not well-suited for practical engineering talents in chip design and manufacturing. This study uses Kolb's Learning Theory as the analytical framework to systematically examine the impact mechanism of experiential learning processes on the formation of practical high-order cognitive skills among full-stack talents in the chip domain.

RESEARCH DESIGN

Method

Given the novelty of the subject and the inductive nature of the research question, this study adopts an exploratory single-case research method. The rationale for this approach is as follows: (1) Case studies are well-suited for exploring "how" questions, particularly for investigating influence mechanisms [41]. This study focuses on how the experiential learning process in the "One Student, One Chip" project fosters the development of practical higher-order cognitive skills among students in the chip domain, including the underlying process mechanisms. This aligns with the strengths of case study methodology. (2) Drawing on the learning cycle theory, this study examines the stages of the experiential learning process and the practical higher-order cognitive skills developed by students during the project. Since existing literature lacks in-depth insights into this topic, an exploratory case study method is appropriate [42]. (3) A single-case study is a research method that involves the detailed description and analysis of a particular phenomenon. This approach is employed to elucidate the dynamic and complex mechanisms that support the phenomenon, and thereby derive theories or patterns that provide a comprehensive explanation for the observed phenomena. [43].

Selection of case

This study selects the "One Student, One Chip" experiential learning project at the University of Chinese Academy of Sciences (UCAS) as the case subject based on theoretical sampling. The sample selection follows two principles: (1) Typicality Principle: Launched in August 2019, the "One Student, One Chip" project has completed six phases, with its scale expanding significantly. Participating institutions have grown from one university to over 300, and the number of applicants has increased from five in the first phase to more than 2,000 in the sixth phase, with a cumulative total of over 6,000 applicants [44]. The project uses open-source processor chips as the entry point and agile development methods as the experimental approach. The programme integrates Computer Science (CS) and Electronic Information Engineering (EE) courses, establishing a comprehensive teaching process that coordinates both software and hardware. In addition, it connects the entire front-end and back-end workflow. During the project, students engage in real-world full-process design, achieve reflective understanding through teaching assistants and learning communities, and document their progress using the "Learning Records" module on the official website. This process fosters higher-order cognitive skills. Through continuous reflection and summarization, students understand how programs run on the processor chips they designed and transform processor chip code into tape-out layouts. As a result, their skills in problem analysis, system evaluation, independent creation and problem solving are significantly enhanced. The five undergraduate students of the first phase joined the development team of Chinese self-developed open-source advanced RISC-V processor, "Xiangshan," and became key technical contributors. (2) Accessibility of Case Data Principle: The research team maintains close collaboration with UCAS, and team members have conducted extensive interviews, field research, and data collection for the project, obtaining detailed and comprehensive data.

Data collection

To ensure the reliability and validity of the case data, the research team collected both primary and secondary data through multiple channels to achieve data triangulation [45]. The data sources include: (1) Interview Data: To gather primary data, we conducted onsite visits to the University of Chinese Academy of Sciences (UCAS) and performed semi-structured interviews with six individuals, including professors and students involved in the "One Student, One Chip" project. (2) Online Data: We accessed the official website of the project (https://ysyx.oscc.cc/) and collected materials from modules such as "Course Materials" and "Learning Records," as well as from mainstream media reports. (3) Literature Data: Relevant papers and monographs were collected through the CNKI and Web of Science.

Data analysis

The coding techniques in grounded theory are highly operational, bridging empirical data and theoretical construction while promoting their alignment, which is beneficial for educational research [46]. Based on this, we adopt the procedural grounded theory proposed by Strauss to conduct data coding, specifically "open coding, axial coding, and selective coding" [47]. The aim is to extract core information at various levels from the extensive textual data and clarify the analytical framework. First, open coding was used to form initial categories. We reviewed all raw data, filtered content relevant to the themes of the experiential learning process and the cultivation of higher-order cognitive skills in engineering students, and then used Nvivo qualitative analysis software for coding, resulting in 19 initial categories. Next, the initial categories were interpreted and aggregated to construct subcategories. To ensure coding objectivity, the team iteratively refined the initial categories and subcategories based on the principle of falsifiability, resulting in 8 subcategories. Finally, the subcategories were aggregated to construct main categories. Through this process, we derived two main categories: "experiential learning spiral" and "practical higher-order cognitive skills."

Table1. Coding Structure

Main category	Subcategory	Initial category
Experiential learning spiral	Concrete experience	Five-stage pipeline experience
		Chisel formal verification experience
		SoC physical design integration experience
		Runtime testing experience
	Reflective observation	Reflection and communication within study groups
		Teaching assistant-guided reflection
	Abstract conceptualization	Learning log documentation
		Code log documentation
	Code design experimentation	Practical bug troubleshooting
		Custom OS development
	Evaluation and verification experimentation	Unit verification
		Integration verification
		Performance verification
		Code evaluation
	Layout design experimentation	Circuit construction
		Circuit optimization
	Reverse testing operation experimentation	Basic board testing
		Board system debugging
Practical higher-order cognitive skills	Problem analysis skills	Disassembly and analysis skills
		Comprehensive analysis skills
	System evaluation skills	Evaluation of existing issues
		Future path assessment
	Independent creation skills	Real-world application of theoretical knowledge
		Overall product design
	Problem-solving skills	Trade-off decision-making skills
		Continuous improvement skills

FINDINGS

Experiential learning spiral

To train professionals with specialized theoretical knowledge and practical experience in chip architecture design, the University of the Chinese Academy of Sciences launched the "One Student, One Chip" experiential project, give acess to students from all domestic universities. Through systematic analysis of secondary data and interview materials, we integrate Kolb's experiential learning theory to propose the concept of a spiral experiential learning model. Specifically, experiential learning is depicted as a spiraling process, where students follow the sequence of engineering workflows and engage in corresponding experiential learning cycles at different stages, with each cycle building upon the previous one. Based on the implementation process of the "One Student, One Chip" project, this study divides the project into four experiential learning cycles. Within each cycle, the phases of "concrete experience" and "active experimentation" are subject to variation, while the "reflective observation" and "abstract conceptualization" phases remain constant. The detailed cyclical process is illustrated in Figure 3.

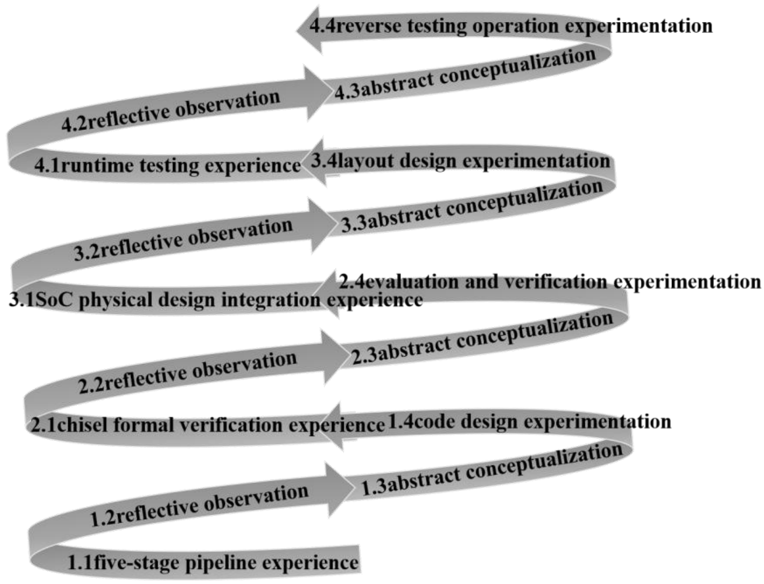

Figure3. Experiential learning spiral

The "One Student, One Chip" experiential learning project adopts a student-led approach. Students follow the chip design process and engage in independent experiences at various stages. These include the five-stage pipeline experience during the code design phase, Chisel formal verification during the code evaluation and verification phase, SoC-based physical design during the layout design phase, and runtime testing during the post-fabrication testing phase. A participant from the third phase noted: "I had heard of niche programming languages like Chisel before and decided to avoid them. However, due to the requirements of the 'One Student, One Chip' project, I learned and applied the Chisel language, developing an out-of-order pipeline for RV64I in less than two months."

The reflective observation phase focuses on helping students reflect on and understand their experiences through various methods. First, learning groups are established. Currently, Sig groups and open-source IP projects have been formed, covering topics such as "High-Performance Architecture Simulator," "Open-Source IP Component Library,""Open-Source Processor Cores," "Open-Source Chip Datasets," "Open-Source RTL Simulator," and "International Communication and Translation." Students form teams to tackle topics of interest, engaging in collaborative learning and reflecting on their experiences within the group. Second, a teaching assistant (TA) system is implemented. The project employs a "students teaching students" approach, selecting experienced participants from previous phases as TAs. Through a group learning mechanism, TAs actively participate in creating learning community. The TA-to-student ratio is approximately 1:30, with online guidance for front-end design and offline guidance for SoC internships. TAs provide key knowledge node guidance and encourage independent reflection. According to the official website: "The TA team schedules weekly online meetings to hear progress reports from each student, with one minute allocated per student for targeted Q&A sessions."

The abstract conceptualization phase is a distinctive feature of the project. Students document the entire process using a specified template, summarizing and abstracting their perceptions and thoughts from the chip design experience and interactive reflection. During this phase, students complete detailed learning logs and code logs, covering experimental issues, processes, operational experiences, and other relevant information. All students must keep writing logs and submit them on the project website every 1-3 days in the specified format. They also report their progress to TAs weekly. If a student fails to update their records for two weeks without notice and provides no feedback after being contacted by their TA, they are automatically considered withdrawn from the program [48]. The project website features a "Learning Records" module, where all records are uploaded to "Tencent Docs" for public archiving.

The active experimentation phase requires students to translate their experiential knowledge, reflective insights, and abstract conceptualizations into tangible products, achieving the transformation from conceptual to material outcomes. In the project, this phase includes four stages: code design practice, evaluation and verification practice, layout design practice, and post-fabrication testing practice. Relevant evidences are presented in Table 2.

Table2. Case evidence from various stages of active experimentation

Subcategory	Evidences
Abstract conceptualization	After participating in the project for over eight months, the student documented that they had fixed several bugs and temporarily removed the paging functionality implemented during PA4.
Code design practices	Unit verification has passed, and after interconnection, the dummy verification is running. Currently, some signals are correct, but there are still errors in the behavior of other signals.
Evaluation and verification practices	The entire process of the third phase of the "One Student, One Chip" project, including SoC and physical design, was completed independently by the students.
Layout design practices	The biggest issue was with the Ethernet port. There was a

	soldering problem in the network transformer circuit of the mt7621, which caused subsequent network connectivity issues. It took a long time to troubleshoot before discovering that it was a hardware problem.

During the code design practice, students adhere to design principles such as the Single Responsibility Principle and the Open/Closed Principle. They adopt design patterns like the Strategy Pattern and Factory Pattern to enhance maintainability and extensibility, eliminate obvious bugs, and independently develop a set of code programs to support chip operation.

In the evaluation and verification practice, students focus on assessing and validating their self-designed code to ensure the fluent progression of subsequent layout design, tape-out, packaging, and post-fabrication testing. This primarily includes unit verification, which involves writing test cases to validate the functionality of each module; integration verification, which ensures the performance of interfaces between modules and their collaborative operation; performance verification, which evaluates the efficiency of the code; and code review, which identifies potential errors through systematic inspection.

The layout design practice involves transforming circuit diagrams into physical layouts in integrated circuit design. During this practice, students in the “One Student, One Chip” project use professional software (e.g., L-Edit) to draw components such as transistors and wires. They also address critical issues in layout design, including thermal effects, current density, dimensional matching, and signal integrity, by proposing and implementing optimization strategies.

The post-fabrication testing practice is conducted after the chip has been fabricated, with the primary goal of ensuring that the chip operates correctly with the embedded system post-packaging. This includes two main tasks: basic board testing and board system debugging. Specific operations involve checking soldering and component quality, measuring impedance, system boot testing, contact-based power-up, using oscilloscopes, and power supply debugging. Students must pay close attention to testing and adopting effective problem-solving methods when problems arise. If not, the entire chip design and manufacturing project will face failure.

Practical higher-order cognitive skills

Based on student feedback on their learning experiences, the comprehensive and progressive nature of the experiential learning process has significantly enhanced their ability to address complex engineering practices, such as integrated circuit design. We systematically analyze interview data from students who participated in the “One Student, One Chip” project and proposes a conceptual framework for practical higher-order cognitive skills. The framework comprises four dimensions: problem analysis, system evaluation, independent creation, and problem-solving. Unlike traditional higher-order cognitive skills, these dimensions are distinctly practice-oriented, emphasizing their connection to real-world applications rather than remaining purely theoretical. Supporting evidence are provided in Table 3.

Table3.Case evidence from Practical higher-order cognitive skills

Subcategory	Evidences
Problem analysis skills	For a complex problem, such as processor design, the A-line and B-line are intricate. However, through this project-based learning, I have learned to break down complex problems into multiple stages, each with its own specific focus and tasks.
System evaluation skills	Through multiple verifications of the self-designed code program, I have gained a certain level of foresight regarding the success of the subsequent tape-out process.
Independent creation skills	We need to translate the programs in the computer into physical layouts, including the arrangement of transistors and circuits, much like manufacturing a complete product.
Problem-solving skills	If the output signal contains frequencies and amplitudes similar to power supply noise, it is necessary to consider whether power supply filtering should be implemented.

Problem analysis skills are demonstrated through Disassembly and analysis skills and comprehensive analysis skills. Students can break down complex engineering problems encountered in real-world integrated circuit practices into independent, non-interfering modules, facilitating step-by-step analysis. Additionally, based on real-world chip design challenges, students can comprehensively evaluate the functionality of each module in code design, considering factors such as operational risks, performance, and costs. System evaluation skills are shaped by both theoretical knowledge and practical experience. These skills involve the ability to verify and assess a project or system, including evaluation of existing issues and future path assessment. Evaluation of existing issues play a critical role in assessing real-world problems. Through repeated integration verification of program modules, students develop a foundational understanding of individual module performance and their integrated functionality. Future path assessment is the student's basic prediction of events that have not yet occurred and is influenced by both theoretical knowledge and practical experience. Independent creation skills encompass the ability to translate theoretical knowledge into practical applications and the skill to design a complete product. The former involves applying abstract concepts to solve real-world problems, transforming knowledge into actionable solutions. The latter refers to students’ ability to modify existing models and innovate to develop functional engineering products. In the “One Student, One Chip” project, students gain a systematic understanding of processor core design across project phases, allowing them to adjust physical structures and ensure the fluent operation of virtual programs, as illustrated in Figure 4.

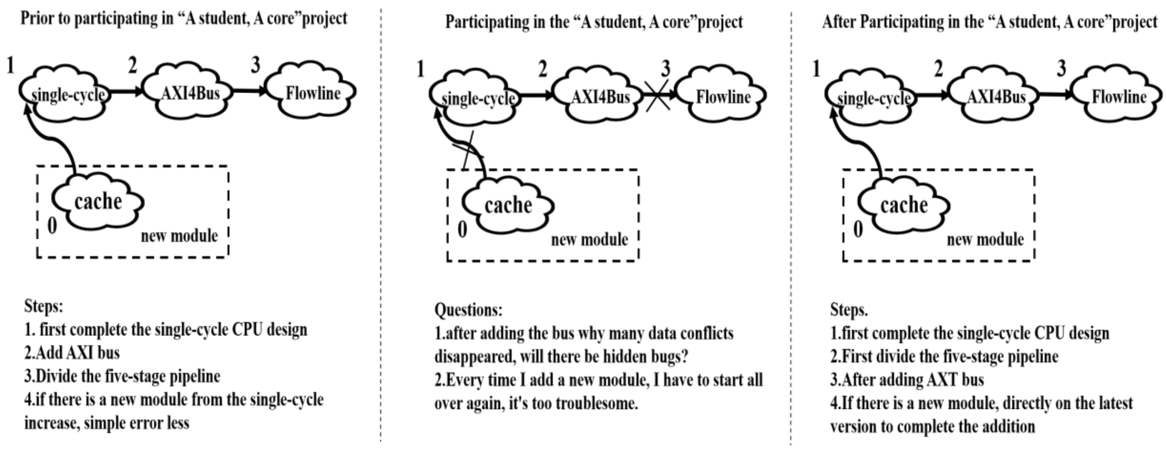

Figure4. Example of the enhancement of independent creation skills

Problem-solving skills represent a new addition to the traditional framework of higher-order cognitive skills. We identify them as a distinct capability, developed through engagement with specific practical activities, and considers them a primary driver for advancing practice. These skills encompass trade-off decision-making skills and continuous improvement skills. Trade-off decision-making skills refers to the capacity to propose and implement solutions for complex problems, grounded in real-world complexities and emphasizing actionable measures. Continuous improvement skills focuses on the iterative refinement of implemented solutions, ensuring the adoption of optimal measures through ongoing evaluation and adjustment.

DISCUSSION

Experiential learning is a spiraling upward process

We introduce the concept of the experiential learning spiral. Specifically, in experiential learning projects related to chip design and manufacturing, the four stages-concrete experience, reflective observation, abstract conceptualization, and active experimentation-collectively form a coherent learning process. However, this process is neither a single cycle nor a parallel occurrence; instead, it represents an endlessly evolving spiral progression. Kolb argues that experiential learning is not linear but spiral, and educators can enhance students' ability to apply knowledge by intentionally designing progressively challenging experiences [49]. Focusing on chip design and manufacturing, we elaborate on the experiential learning spiral. On one hand, learning cycles are multi-layered spiral processes, but their sequence is significantly influenced by actual engineering stages. Educators' designs for experiential learning are not isolated but are shaped by engineering practice procedures. In chip design and manufacturing, multiple spirals emerge based on integrated circuit processes, such as "design, verification, layout, and testing." Each experience triggers reflection, conceptualization, and application, forming a cycle. On the other hand, each learning spiral is interconnected and follows a progressive logic. One spiral builds upon the previous one, with the learner's experience and skills from the prior cycle influencing the concrete experience of the next, thereby initiating the subsequent spiral. For instance, in chip design and manufacturing, students develop problem analysis skills during the first learning cycle, which lays the foundation for verification and evaluation experiences in the next cycle.

Higher-order cognitive skills are practice-oriented

Current research actively investigates the relationship between practical skills and cognitive skills, yet there is insufficient evidence to confirm a strong correlation between the two, and the nature of their interaction remains debated [50]. Traditional theories of cognitive skills primarily focus on psychological and cognitive skills [51], with limited emphasis on their connection to real-world practices. We introduce the concept of practical higher-order cognitive skills, proposing that analytical skills, evaluative ability, creative ability, and problem-solving skills are closely tied to engineering practice. This connection is also influenced by the final stage of the experiential learning cycle, "active experimentation" [52]. Specifically, higher-order cognitive skills developed by professionals in the chip field are shaped through engineering practice, representing cognitive generalizations and preserved thinking about specific practical behaviors. For example, analytical ability involves examining the stages and overall operations of engineering projects, evaluative skills are based on judgments about the feasibility of real-world engineering projects, creative skills translate abstract thinking into tangible engineering products, and problem-solving addresses challenges encountered during practice. In summary, higher-order cognitive skills are not abstract constructs but are grounded in practice, sharing the complexity, objectivity, and systematicity of real-world engineering problems.

The linear effect and progressive development of "experience-experimentation-skill"

Through exploratory research, we identify both linear influences and progressive developmental trends among concrete experience, active application, and cognitive skills within the experiential learning cycle (Figure 5).

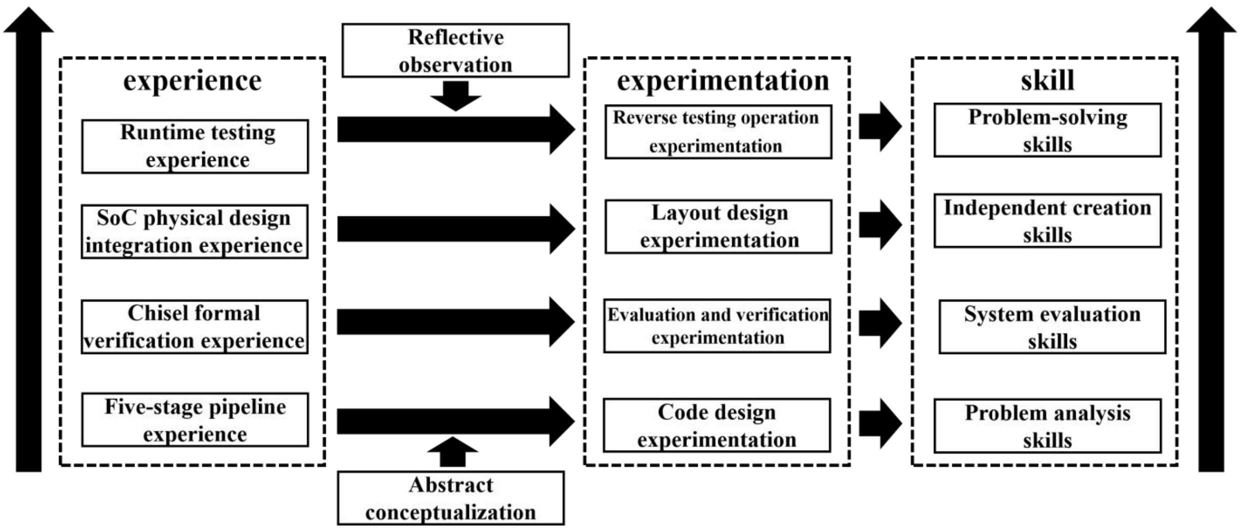

Figure5. "experience-experimentation-skill" model

On one hand, concrete experience directly guides learners to engage in reflective observations and abstract generalizations, influencing active application behaviors and fostering the development of various skills. Existing research often treats the four-stage learning spiral as an interconnected whole, with each stage closely linked [53], [54]. However, through exploratory case research, we find that the stages of "reflective observation' and "abstract generalization" function as inherent components, operating similarly across different learning spirals. Consequently, the study proposes that experience has a more direct influence on action and ability, introducing a linear "experience-practice-skill" model by excluding reflection and abstraction stages. Specifically, different concrete experiences shape learners' application actions, and the focused training during these actions directly cultivates differentiated practical skills. On the other hand, due to the upward spiral of experiential learning, ability development follows a progressive trend. This is exemplified in the comprehensive training of full-stack talents in the chip field. Students develop problem analysis skills through code design, system evaluation skills through assessment and verification, and autonomous creative skills through layout design. Finally, the practice of backtesting, which means systematically solving real-life problems encountered after chip packaging, focuses on the development of problem-solving skills represented by trade-off decision-making skills and continuous improvement skills. The problem analysis ability and other abilities are also exercised, but they are more of a preparation for the problem solving ability.

CONCLUSION

In conclusion, we takes the experiential learning project "One student, One chip" of the University of Chinese Academy of Sciences as the research object, adopts the exploratory case study method to construct two concepts: "experiential learning spiral" and "practical higher-order cognitive skills", and preliminarily verifies the effect of experiential learning spiral on the practical higher-order cognitive skills of full-stack talents in the field of chip. We found that experiential learning is a spiral process, higher-order cognitive skills are practice-oriented, and "experience-experimentation-skill" is both a linear conduction relationship and a progressive development trend. This study preliminarily explores the effect of experiential learning on the practical higher-order cognitive skills of engineering talents in a specific field (chip design and manufacturing), and provides new perspectives for related research.

LIMITATIONS AND PROSPECTS

While this study provides an in-depth analysis of how spiral experiential learning programs influence the practical higher-order cognitive skills of students specializing in chip design and manufacturing, several areas need further exploration. First, we adopt a single-case approach, focusing on the impact of experiential learning spirals in chip design and manufacturing on professionals in this field, which limits the generalizability of the findings. Future studies should incorporate experiential projects from diverse engineering disciplines, increase the number of cases, and identify a more universal process mechanism through which experiential learning spirals shape the practical higher-order cognitive skills of engineering students. Second, this study employs qualitative case study analysis, relying on interview data to infer causality without standardized data analysis methods. The presentation of evidence and data interpretation are selective and subjective, requiring further validation of reliability.. Future research should also clarify the operational definitions of variables and construct an empirical model based on multi-level theories to better explain the mechanisms by which spiral experiential learning programs influence the practical higher-order cognitive skills of engineering students.

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REFERENCES

[1] C. K. Y. Chan and K. K. W. Lee, "Constructive alignment between holistic competency development and assessment in Hong Kong engineering education," *Journal of Engineering Education*, vol. 110, no. 2, pp.437-457, 2021.

[2] N. D. Q. Nguyen, "The essential skills and attributes of an engineer: A comparative study of academics, industry personnel and engineering students," *Global J. of Engng. Educ*, vol. 2, no. 1, pp. 65-75, 1998.

[3] E. Krylov and S. Devyaterikov, "Developing students' cognitive skills in MMS classes," *STEM Education*, vol. 3, no. 1, pp. 28-42, 2023.

[4] M. Pinho-Lopez, M. and J. Macedo, " Project-based learning to promote higher order thinking and problem-solving skills in geotechnical courses," *International Journal of Engineering Education*, Vol. 4, No 5, pp. 20-27, 2014.

[5] C. S. Sankar, V. Varma, and P. K. Raju, "Use of case studies in engineering education: Assessment of changes in cognitive skills," *Journal of Professional Issues in Engineering Education and Practice*, vol. 134, no. 3, pp. 287-296, 2008.

[6] D. F. Saleh, S. A. Bilhassan, R. S. Omran, et al., "Evaluating Cognitive Skills Development in Undergraduate Engineering Students: A case study utilizing the EAS Test," *IOSR Journal of Engineering*, vol. 14, no. 8, pp. 26-31, 2024.

[7] A. Khanlari, "Robotics integration to create an authentic learning environment in engineering education," in *2016 IEEE Frontiers in Education Conference (FIE)*,2016.

[8] "New engineering education transformation," Massachusetts Institute of Technology, https://neet.mit.edu/, Aug. 2024. [Accessed Nov. 2024].

[9] "About the NEET Program," Massachusetts Institute of Technology, https://neet.mit.edu/about/program, Aug. 2024. [Accessed Nov. 2024].

[10] J. E. Mitchell, A. Nyamapfene, K. Roach, et al., "Faculty wide curriculum reform: the integrated engineering programme," *European Journal of Engineering Education*, vol. 46, no. 1, pp. 48-66, 2021.

[11] R. L. Tang, B. Z. Liang, and L. M. Zhou, "Redesign of higher engineering education for complex systems - The practice of SDIM's 'deep integration' new engineering education at Southern University of Science and Technology," *Research in Higher Engineering Education*, no. 5, pp. 41-47, 2023.

[12] L. N. Zheng, Y. Han, J. X. Ye, et al., "Construction of talent training program in future technology colleges - Based on the practice and exploration at Beihang University," *Research in Higher Engineering Education*, no. 5, pp. 19-25, 2022.

[13] W. Zhang, P. Y. Xu, and Y. C. Lin, "Characteristic paths to independently cultivate outstanding engineers - A multi-case study on the construction of integrated circuit science and engineering interdisciplinary in China," *Research in Higher Engineering Education*, no. 6, pp. 42-48, 2024.

[14] D. S. Yu, S. J. Hu, X. C. Zou, et al., "Difficulties and strategies for integrated circuit talent training in research universities - A case study of the educational reform of integrated circuit design and integrated system major at Huazhong University of Science and Technology," *Research in Higher Engineering Education*, no. 3, pp. 52-59, 2022.

[15] J. Wu, Y. Liu, and T. Luo, "Research on Talents Training Mode for integrated circuit major under the Background of the Science-education and Industry-education Integration," in *SHS Web of Conferences,*

EDP Sciences, 2023.
[16] Y. X. S. Sun, Q. Zhu, and J. M. Case, "Preparing Future Semiconductor Talent in the Global Context: A Comparative Study of the Semiconductor Engineering Curriculum in the US and Taiwan," in *ASEE Annual Conference & Exposition*, 2024.
[17] Ministry of Education, Ministry of Human Resources and Social Security, and Ministry of Industry and Information Technology, "Guidelines for the Development of Manufacturing Talents," Chinese Government Website, https://www.gov.cn/xinwen/ 2017-02/24/content_5170697.htm, Feb. 2017. (Accessed Nov. 2024).
[18] R. J. Kraft, "Toward a theory of experiential education," *The Theory of Experiential Education*, vol. 2, pp. 7-38, 1986.
[19] C. M. Itin, "Reasserting the philosophy of experiential education as a vehicle for change in the 21st century," *Journal of Experiential Education*, vol. 22, no. 2, pp. 91-98, 1999.
[20] D. A. Kolb, Experiential Learning: Experience as the Source of Learning and Development. Englewood Cliffs, NJ: Prentice-Hall, 1984.
[21] D. A. Kolb, Experiential Learning: Experience as the Source of Learning and Development. FT Press, 2014.
[22] W. James, The Principles of Psychology. New York: Henry Holt, 1890.
[23] J. Heikkinen and V. Isomöttönen, "Learning mechanisms in multidisciplinary teamwork with real customers and open-ended problems," *European Journal of Engineering Education*, vol. 40, no. 6, pp. 653-670, 2015.
[24] H. Li, A. Öchsner, and W. Hall, "Application of experiential learning to improve student engagement and experience in a mechanical engineering course," *European Journal of Engineering Education*, vol. 44, no. 3, pp. 283-293, 2019.
[25] S. Budihal, U. Patil, and N. Iyer, "An integrated approach of course redesign towards enhancement of experiential learning," *Procedia Computer Science*, vol. 172, pp. 324-330, 2020.
[26] M. Abdulwahed and Z. K. Nagy, "Applying Kolb's experiential learning cycle for laboratory education," *Journal of Engineering Education*, vol. 98, no. 3, pp. 283-294, 2009.
[27] L. Fewster-Thuente and T. J. Batteson, "Kolb's experiential learning theory as a theoretical underpinning for interprofessional education," *Journal of Allied Health*, vol. 47, no. 1, pp. 3-8, 2018.
[28] D. S. Yu, S. J. Hu, X. C. Zou, et al., "Difficulties and strategies for integrated circuit talent training in research universities - A case study of the educational reform of integrated circuit design and integrated system major at Huazhong University of Science and Technology," *Research in Higher Engineering Education*, no. 3, pp. 52-59, 2022.
[29] Y. Xu and J. A. Liu, "Competence perspective on key core technology talent training - The role mechanism of the OOICCI model," *Research in Higher Engineering Education*, no. 3, pp. 67-73, 2023.
[30] B. Ji, Y. Liu, Y. Wang, et al., "Research on the Multidimensional Integration of Talent Cultivation in the Field of Electronic Information," *International Journal of New Developments in Education*, vol. 5, no. 21, pp. 177-184, 2023.
[31] M. Ye, L. Sun, and J. Shen, "Cultivation of innovative talents with information characteristics for engineering education orientation," in *International Conference on Engineering Education and Information Technology (EEIT)*, 2022.
[32] T. Wang, "Teaching Reform and Exploration of Mono-Chip Computers Course for Engineer Education," *International Journal of Trend in Research and Development*, vol. 8, no. 3, pp. 106-107, 2021.
[33] B. S. Bloom and D. R. Krathwohl, Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook I: Cognitive Domain. New York: Longmans, Green, 1956.
[34] L. W. Anderson and D. R. Krathwohl, A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. New York: Longman Publishing, 2001.
[35] National Research Council, A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, D.C.: The National Academies Press, 2012.

[36] T. Long, N. T. Nguyen, N. T. H. Yen, and N. V. Hanh, “The Role of Experiential Learning and Engineering Design Process in K-12 STEM Education,” *International Journal of Education and Practice*, vol. 8, no. 4, pp. 720-732, 2020.
[37] Z. Siddique, A. Bradshaw, P. Hardré, et al., “Experiential Learning Based Engineering Curriculum to Develop Meta-Competencies,” in *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 2011.
[38] K. S. Sangwan and R. Singh, “An experiential learning-integrated framework to improve problem-solving skills of engineering graduates,” *Higher Education, Skills and Work-Based Learning*, vol. 12, no. 2, pp. 241-255, 2022.
[39] L. Howatson-Jones, Reflective Practice in Nursing. Learning Matters, 2016.
[40] M. McLoughlin and A. Darvill, “Peeling back the layers of learning: a classroom model for problem-based learning,” *Nurse Education Today*, vol. 27, no. 4, pp. 271-277, 2007.
[41] K. M. Eisenhardt, “Building Theories from Case Study Research,” *Academy of Management Review*, vol. 14, no. 4, pp. 532-550, 1989.
[42] R. K. Yin, Case Study Research: Design and Methods. Sage Publications, 2009.
[43] K. M. Eisenhardt and M. E. Graebner, “Theory building from cases: opportunities and challenges,” *Academy of Management Journal*, vol. 50, no. 1, pp. 25-32, 2007.
[44] C. Zhang ,Y. Gao, “University of Chinese Academy of Sciences Implements the ‘One Student, One Chip’ Program, Expanding to Over 300 Universities—Breaking the ‘Shell’ for Chip Talent,” China Education News, https://baijiahao.baidu.com/s?id= 1807890340534016858, Apr. 2024 (Accessed Nov. 2024).
[45] T. A. Scandura and E. A. Williams, “Research methodology in management: Current practices, trends, and implications for future research,” *Academy of Management Journal*, vol. 43, no. 6, pp. 1248-1264, 2000.
[46] X. Chen, “Exploration of the application of grounded theory in Chinese educational research,” *Peking University Education Review*, vol. 13, no. 1, pp. 2-15, 2015.
[47] J. Corbin and A. Strauss, Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. Sage Publications, 2014.
[48] Y. R. Xu, J. A. Liu, B. W. Jie, et al., “The logic and mechanism of cultivating key core technology talents through the integration of science and education - Analysis of the OOICCI chip talent training program,” *Research in Higher Engineering Education*, no. 1, pp. 20-26+43, 2023.
[49] A. Kolb and D. Kolb, “Eight important things to know about the experiential learning cycle,” *Australian Educational Leader*, vol. 40, no. 3, pp. 8-14, 2018.
[50] I. M. J. Van der Fels, S. C. M. Te Wierike, E. Hartman, et al., “The relationship between motor skills and cognitive skills in 4-16 year old typically developing children: A systematic review,” *Journal of Science and Medicine in Sport*, vol. 18, no. 6, pp. 697-703, 2015.
[51] D. R. Krathwohl, “A Revision of Bloom’s Taxonomy: An Overview,” *Theory into Practice*, vol. 41, no. 4, pp. 212-218, 2002.
[52] C. Beard, The Experiential Learning Toolkit: Blending Practice with Concepts. Kogan Page Publishers, 2010.
[53] J. E. Zull, The Art of Changing the Brain: Enriching Teaching by Exploring the Biology of Learning. Sterling, VA: Stylus Publication, 2002.
[54] A. Y. Kolb and D. A. Kolb, “Experiential learning theory: A dynamic, holistic approach to management learning, education and development,” *The SAGE Handbook of Management Learning, Education and Development*, vol. 7, no. 2, pp. 42-68, 2009.