# Teaching Design of Critical Thinking in Microelectronics Experimental Courses

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**Abstract.** The application of critical thinking in education has a wide range of significance and value. In order to meet the changing market demand and technological environment, it is urgent to strengthen the cultivation of critical thinking for microelectronics talents. The article takes the microelectronics experimental course as an example and introduces how to consciously strengthen the cultivation of students' critical thinking through teaching design in classroom teaching from several aspects, such as problem formulation, verification scheme, and optimal design. Finally, the article introduces some challenges and countermeasures to the cultivation of critical thinking.

**Keywords:** Teaching Design · Critical Thinking · Microelectronics Experiment

## 1 Introduction

Critical thinking is widely considered to be one of the most important qualities in the 21st century. Critical thinking is a way of thinking that enables one to effectively evaluate, analyze, question, and improve on one's own and others' opinions, reasons, evidence, and conclusions in the process of thinking [1, 2]. Critical thinking can help people avoid thinking misconceptions such as blind obedience, bias and misunderstanding, improve the quality and efficiency of thinking, and enhance innovation and problem-solving skills [3]. Microelectronics technology refers to the technology of manufacturing integrated circuit chips with semiconductor materials and processes at the micron or nano level. As a frontier field of science and technology development in the world today, microelectronics technology is also an important emerging direction for national economic and social development. With the rapid development of information technology, communication technology, artificial intelligence and other emerging fields, the microelectronics industry is facing increasingly fierce international competition and increasingly complex technical challenges, putting forward higher requirements for microelectronics talents. Critical thinking can help microelectronics talents improve design quality and efficiency in design practice, improve learning effectiveness and level in the learning process, identify the essence of problems and solutions faster, and improve the breadth and depth of


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vision in field expansion, so as to innovate products and technologies that meet market demand and technology trends. In order to cope with the changing market demand and technology environment, microelectronics talents need to strengthen the cultivation of critical thinking.

## 2 The Concept of Critical Thinking and its Teaching Application

Critical thinking refers to the ability to consciously apply skills such as logic, reasoning and analysis when processing information and problems in order to produce accurate, clear and reasonable conclusions. Critical thinking is an advanced cognitive ability that typically includes characteristics such as independent thinking, logical analysis, judgment, creativity, reflection, and communication [4, 5]. The purpose of critical thinking is to discover the nature of problems and ways to solve them through a purposeful, structured and logical thinking process. In the field of education, critical thinking is seen as an important competency and skill that can help students better understand and respond to complex problems and challenges in the real world [6]. The main applications of critical thinking in education include the following:

- Curriculum design: Critical thinking can be applied to curriculum design in the teaching and learning process. Teachers can design lessons to guide students to look at problems from different perspectives and to promote the use of critical thinking to analyze and solve problems. For example, students can be guided to understand the logic and meaning inherent in the material by asking questions, reasoning, analyzing and generalizing when reading the material.
- Teaching methods: Critical thinking can also be used to various teaching methods. For example, in discussion and interactive teaching methods, teachers encourage students to think and ask questions to enhance their ability to develop pathways to analyze the origin of problems; in case study and problem solving methods, teachers can help students acquire critical thinking skills by guiding them to come up with their own solutions to cases and problems.
- Assessment approaches: Critical thinking can be applied to improve traditional assessment methods. As an example, teachers can use open-ended questions to encourage students to demonstrate their critical thinking skills and thus assess their thinking and presentation skills [5]. By assessing students' critical thinking skills, teachers can better understand students' learning and abilities and thus improve their teaching methods more effectively.

## 3 Teaching Design of Microelectronics Experiment Courses

The Design of Microelectronic Science and Engineering is an important course in the practical ability cultivation of our microelectronic science and engineering students. The course revolves around practical teaching of integrated design projects of microelectronics and integrated circuits. The purpose of the course is to help students become familiar with the methods, processes and procedures related to the design of microelectronic devices and integrated circuits through a series of design experiments with clear objectives, open processes and progressive levels, and to master the basic skills required for the

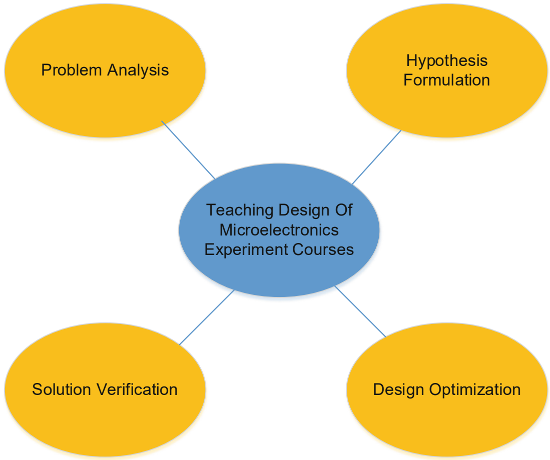


**Fig. 1.** Aspects of teaching design

design and implementation of microelectronic devices and integrated circuits. Students will be exposed to a number of experimental topics developed from industrial needs, from which they will select topics suitable for their professional direction (devices and processes, analog integrated circuits, digital integrated circuits) to carry out their designs. Students will be exposed to a number of experimental topics developed from industrial needs, from which they will select topics suitable for their major direction (devices and processes, analog ICs, digital ICs) to carry out design. In the design of this course, we consciously strengthen the cultivation of critical thinking from several aspects: problem analysis, hypothesis formulation, solution verification, and design optimization as Fig. 1 shown.

### 3.1 Problem Definition and Analysis

In microelectronics design practice, the first thing to do is to clearly define and analyze the problem. This requires the use of critical thinking to summarize, classify, sort out, abstract, and other operations to find out the essential, critical, and difficult points of the problem, and to avoid being influenced by irrelevant information or preconceived concepts. In the project "CMOS operational amplifier design" in this course, students have to independently select the appropriate circuit architecture and device parameters to build an operational amplifier that meets the specification requirements. During the experimental process, students often encounter that the output of the simulated circuit does not meet the expectation. In this case, the teacher needs to consciously guide the students to use critical thinking to find the root cause of the problem. The following is a specific design of the teaching process:

- Define the problem: The output of the circuit does not meet the expectation and the cause of the problem needs to be found. In microelectronics experimental design, problem definition is a crucial step. Problem definition requires a clear understanding of the experiment's goals, specific problems that need to be solved, and the data and experimental conditions needed. For students, problem analysis requires starting from the principles and basic knowledge of the experiment, combining with experimental phenomena and data to discover the essence and key points of the problem, and then finding the direction and methods to solve the problem. Teachers can guide students to think and explore, help them discover problems, encourage students to identify and analyze problems, and provide necessary guidance and assistance to help students solve problems and better understand the principles and characteristics of the experiment.

- Analyze the problem: Students first need to determine what the expected output of the circuit is (e.g., voltage amplitude, frequency, etc.) so that they can understand what aspects of the output do not meet expectations. Then, lead the students to check all parts of the circuit to make sure they are all working properly. If all parts of the circuit are working properly, and further guide students to think about other factors that may be causing the problem, such as power supply noise, grounding issues, etc.
- Sort out the problem: In this step, the teacher can use a mind map or other diagramming tool to categorize and sort out the problem in order to give students a better understanding of the nature and key of the problem. For example, the teacher can divide the op-amp circuit into parts and find the part where the output does not meet the expectation, and then refine the cause and solution of the problem.
- Abstract problem: In this step, students need to discard details and focus on the essence and root cause of the problem. For example, in a simulated circuit, the output does not meet expectations may be due to fluctuations in the supply voltage. In this case, students will need to design a more stable power supply or use more advanced power supply voltage regulation techniques to solve the problem.

Through the above process, the teacher guides students to find the root cause of the problem by defining the problem, analyzing the problem, sorting out the problem and abstracting the problem. In this process, students not only acquire professional knowledge, but also learn to use critical thinking to analyze and solve the problem.

### 3.2 Propose Design Solutions and Verification

After the above problem formulation and analysis process, teachers need to guide students to further develop reasonable and feasible hypotheses or solutions based on the problem, and to verify and evaluate them. In this process, students need to learn to apply critical thinking to logical reasoning, evidence support, and risk assessment of the hypothesis or solution, and to avoid being influenced by emotional tendencies or authoritative pressure. Again, using the above topic as an example, suppose students find the output gain of an amplification circuit unstable during an experiment. The following is the design of the specific teaching process (as Fig. 2 shown):

- Hypothesis or scenario: In microelectronics experimental design, formulating a hypothesis or scenario is a critical step in the process. A hypothesis is an educated guess or tentative explanation that is used to guide the experiment and help determine the expected results. The hypothesis should be based on the knowledge and understanding of the underlying principles and theories related to the experiment. To

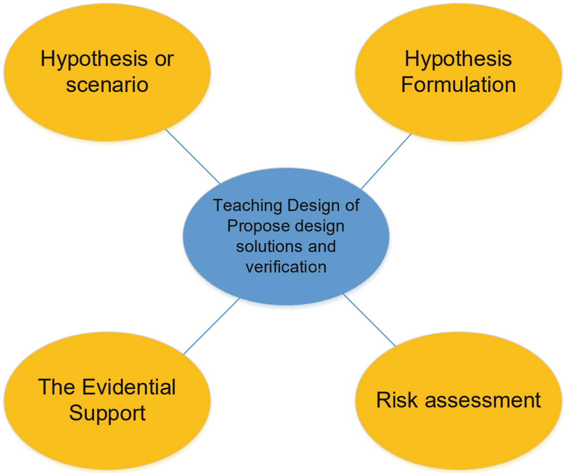


**Fig. 2.** Teaching design of Propose design solutions and verification

develop a hypothesis, students should carefully review the experimental objectives and available resources, and identify the key variables that may affect the experiment outcome. They should then use their knowledge of the principles and theories related to the experiment to make an educated guess about how these variables will interact with each other, and how this will affect the experiment results. Teachers can help guide students in formulating a hypothesis by providing examples of previous experiments, as well as explaining the underlying theories and principles related to the experiment. They can also encourage students to test multiple hypotheses or scenarios to help them gain a deeper understanding of the experiment and its underlying principles. Based on the failure phenomenon of the circuit, the teacher first guides the students to analyze how many possible reasons for the unstable gain of the circuit? It is assumed that the main reason is due to the unstable bias current of the MOS tube. To solve this problem, students can use a feedback circuit to stabilize the bias current.

- Logical reasoning: Here students can be led to review the principles of op-amp feedback circuits they have studied in class to strengthen the connection between theory and practice. The feedback circuit can control the bias current by adjusting the value of the feedback resistor. Since the design of the feedback circuit is based on the negative feedback principle, it can make the gain of the circuit more stable and reduce the effects caused by factors such as temperature and device differences.
- The Evidential Support: Next, students are instructed to verify the effectiveness of the feedback circuit through theoretical calculations and simulation experiments. Theoretical calculations can express the effect of the feedback circuit on the gain with equations, and simulation experiments can be simulated by SPICE software to verify the results of theoretical calculations.
- Risk assessment: The design of the feedback circuit requires multiple considerations of the feedback circuit parameters, the architecture of the feedback network, stability and other factors to the circuit. If the feedback circuit is not designed properly, other problems may be introduced, such as oscillation and distortion. This step allows

students to carefully assess the risks of feedback circuits using a variety of approaches and to develop appropriate countermeasures.

Through these steps, students effectively learn how to use critical thinking to propose and verify design solutions. Through the steps of logical reasoning, evidence support, and risk assessment, students can determine the validity and feasibility of a feedback circuit and find the optimal feedback circuit design solution.

### 3.3 Optimization of the Design Solution

After verifying the initial solution, the next step is to optimize and improve the solution based on the verification and evaluation results, and to verify and evaluate it again. In this process, the teacher needs to guide students to use critical thinking to compare and analyze the solution, weigh the advantages and disadvantages, suggest improvements, and avoid being influenced by inertia or sunk costs. Take another lab project in this course, "FPGA-based Digital Signal Processor Design", for example, students need to optimize and improve the design solution, and to verify and evaluate it again. The following steps (as Fig. 3 shown) were used to integrate critical thinking into the experimental process:

- Comparative analysis: Students can first compare and analyze different digital processor designs to evaluate their advantages and disadvantages in terms of power consumption, area, speed, reconfigurability, and so on. For example, students can compare the characteristics of RISC and CISC architectures and evaluate their differences in terms of instruction set, memory access, pipeline structure, number of registers, etc.
- Weighing the advantages and disadvantages: Based on the comparative analysis, students need to weigh the advantages and disadvantages of different design solutions to find the optimal solution so that they can choose the appropriate architecture to achieve the requirements of the topic. In this process, students may find that the RISC architecture has higher performance and lower power consumption, but it has a relatively small instruction set and requires more code to complete complex operations.
- Suggestions for improvement: After determining the optimal design solution, students can next improve and optimize on this basis. There are many optimization measures, including optimizing the pipeline structure, increasing the cache size, and adjusting the instruction set to improve performance and reduce power consumption.
- Re-verification and evaluation: After the improvements and optimizations are made, the instructor needs to guide the re-verification and evaluation of the design solutions to ensure they meet the design requirements. This process can be done using simulators, simulation tools and real-world tests to verify the correctness and performance of the solution.

In the above case study, students can learn to use critical thinking to optimize the design solution by comparing and analyzing, weighing the advantages and disadvantages, suggesting improvements, and re-validating and evaluating.

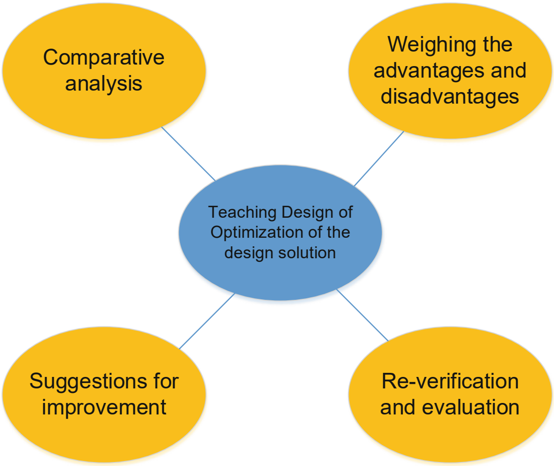


**Fig. 3.** Teaching design of Optimization of the design solution

## 4 Challenges of Critical Thinking Teaching Design

The microelectronics laboratory course is one of the important ways to cultivate microelectronics talents. Through experiments, students can gain a deep understanding of the working principles, characteristics, and performance of microelectronic devices and systems, while also cultivating their practical abilities and critical thinking skills. However, there are also some challenges in cultivating critical thinking skills for microelectronics talent in laboratory courses, mainly including the following points:

- Difficulty of the experiment content: Microelectronics laboratory course content is generally complex and requires students to have a certain level of basic knowledge and skills to complete. This places higher demands on students' self-learning and practical abilities, as well as on the teaching quality of the lab instructor and the level of equipment completeness.
- Uncertainty in the experimental process: Many uncertain factors are involved in the microelectronics experimental process, such as equipment failure and data anomalies. This requires students to have a certain level of adaptability and problem-solving ability, as well as critical thinking and judgment skills, to avoid drawing incorrect conclusions due to uncertain factors.
- Analysis and evaluation of experimental results: The analysis and evaluation of microelectronics experimental results are essential and can help students better understand the principles and characteristics of the experiment while also cultivating critical thinking skills. However, analyzing and evaluating experimental results requires a certain level of professional knowledge and skills, including scientific research methods and data analysis skills.
- Coherence and practicality of the experimental curriculum: Microelectronics laboratory courses are generally divided into multiple modules, each with different experimental content and requirements. To better cultivate students' critical thinking skills,

the laboratory curriculum should have a certain level of coherence and practicality, allowing students to gradually master the working principles, characteristics, and performance of microelectronic devices and systems during the experimental process, while continuously summarizing and improving their skills in practice.

In summary, the difficulty in cultivating critical thinking skills for microelectronics talents in the microelectronics experimental course mainly lies in the complexity of the experimental content, the uncertainty in the experimental process, the analysis and evaluation of experimental results, and the coherence and practicality of the experimental course. Students need to continuously improve their basic knowledge and skills, enhance their problem-solving ability and critical thinking skills through self-learning and practice [7]. In addition, they need to pay attention to safety issues during the experimental process, follow laboratory rules and regulations, and ensure their own safety. For teachers, they need to focus on guiding students' thinking and exploration during the teaching process, and cultivate students' critical thinking skills [8]. They also need to pay attention to the selection and management of experimental equipment and materials, to ensure the quality of the experimental course and its teaching effectiveness. Teachers should establish good relationships with their students, respond to students' questions and needs in a timely manner, and provide necessary guidance and assistance to them [9].

## 5 Conclusions

With the development of information technology and the advent of the information era, we are faced with the challenge of massive and complex information. Critical thinking can foster independent thinking and creativity, help distinguish the authenticity, reliability and value of information sources so as to avoid blindness and misinformation, and improve student's problem-solving skills and resilience, which are crucial to the rapidly changing environment in modern society [10, 11]. Although more and more educational institutions and educators are now focusing on and emphasizing the development of critical thinking, it is not easy to truly develop students with critical thinking skills. The education of critical thinking is a long-term and challenging task that requires the concerted efforts of the educational community and society at large. Only on the basis of continuous reform and innovation can we truly cultivate high-quality talents with critical thinking skills and make greater contributions to the development of our country and society.

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"Exploration of the Artificial Intelligence Technology Empowering the Teaching Evaluation System of College English", Project of the Hunan Provincial Social Science Achievement Evaluation Committee in 2023

## References

1. M. Sun and Z. Li, "Cultivating College Students' Critical Thinking Ability in China," Higher Education of Social Science, vol. 17, no. 2, 2019.
2. H. Z, K. S, and L. E, "Student's critical thinking skills in interactive demonstration learning with web based formative assessment," Journal of Physics: Conference Series, vol. 1567, no. 4, 2020.
3. W. Sun, H. Sun, and W. Gu, "On the Critical Thinking of the Undergraduates and the Cultivating Paths of the Universities in China," Hangzhou, China, 2020, pp. 102–105.
4. M. López et al., "The impact of an educational intervention on nursing students' critical thinking skills: A quasi-experimental study," Nurse Education Today, vol. 85, no. C, 2020.
5. S. I. N, R. I. W, and Y. N. P. M, "Students' critical thinking skills comparison in discovery learning based on constructing concept mapping and mind mapping," Journal of Physics: Conference Series, vol. 1521, no. 4, 2020.
6. A. Buzduga and L. Rodrigues, "Comprehension View about Critical Thinking - Narrative Review," Asian Journal of Education and Social Studies, 2021.
7. M. R. E., "Challenges of Critical Thinking," PsycCRITIQUES, vol. 62, no. 38, 2017.
8. G. Heisserer and PhD, "Thoughts on Thinking: The Challenge of Critical Thinking," In-Sight: A Journal of Scholarly Teaching, vol. 1, 2006.
9. B. M. L, "The challenge of critical thinking," Ohio nurses review, vol. 74, no. 9, 1999.
10. K. I and Caswita, "Students' critical thinking ability in solving contextual problems at a jun-ior high school," Journal of Physics: Conference Series, vol. 1521, no. 3, 2020.
11. S. Jing, "Study on the Characteristics of the Chinese Students' Critical Thinking," Higher Education Research, vol. 5, no. 3, 2020.