# Research on Learning Strategies for Advanced Mathematics Based on Cognitive Load Theory

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**Abstract:** Because of the abstract ideas and strict logical reasoning involved in advanced mathematics courses, students in vocational and technical education often find them hard to understand and master. As a result, they need systematic learning methods and strategies. This paper, based on Cognitive Load Theory, examines the sources of cognitive load in advanced mathematics courses and offers specific learning strategies for students in vocational and technical education. It emphasizes managing intrinsic cognitive load, reducing extraneous cognitive load, and enhancing germane cognitive load. The paper recommends that teachers and students adopt approaches such as tiered instruction, optimized teaching, situated learning, habit formation, collaborative learning, and diverse assessments to boost learning efficiency and teaching effectiveness. By combining theoretical insights with practical advice, this study provides college educators and students with a scientifically supported, practical pedagogical approach and a set of learning strategies. This approach not only improves students' performance in advanced mathematics but also strengthens their independent learning skills and creative thinking.

**Keywords:** Cognitive Load Theory; Vocational and technical education; Advanced Mathematics; Learning strategies

## 1. Introduction

Advanced Mathematics is a core course for freshmen in vocational and technical education, serving as a public basic and compulsory examination course for career development. The teaching hours for advanced mathematics are generally 60 to 80 hours. This course is highly abstract and rigorously logical, making it difficult for students to grasp and understand related knowledge in a short period. Secondly, most vocational and technical education students have weak mathematical foundations, and advanced mathematics contains many abstract concepts. Students lack concrete thinking and are prone to aversion and fear of difficulties, which leads to insufficient learning motivation and low enthusiasm. Furthermore, some teachers use single teaching methods, still adhering to traditional "cramming" teaching models, focusing on one-way knowledge transfer, lacking effective teacher-student interaction and student participation, making it difficult to stimulate students' learning interest and effectively cultivate their independent thinking and problem-solving abilities. In summary, this leads vocational and technical education students to believe that advanced mathematics courses are difficult to understand, master,

and apply.

## 2. Cognitive Load Theory

Cognitive Load Theory (CLT) is a theory of human cognitive architecture proposed by John Sweller in the late 1980s [1]. This theory posits that human memory comprises working memory and long-term memory. Working memory is responsible for processing and manipulating information, and its capacity and duration are limited; long-term memory is responsible for storing a large number of knowledge schemas, which can effectively reduce the load on working memory, and its capacity is unlimited. When learning new knowledge, new information is first stored in working memory, processed and integrated by working memory, integrated into existing schemas, or new schemas are created, and then transferred to long-term memory. If the total cognitive load of a student's working memory exceeds its capacity, learning will be hindered. Therefore, it is necessary to design appropriate learning strategies for advanced mathematics based on the cognitive load students experience during learning. This requires considering how to control and adjust intrinsic cognitive load, extraneous cognitive load, and germane cognitive load [2].

### 2.1. Three types of cognitive load

(1) Intrinsic cognitive load: This load is determined by the complexity of the learning material itself and depends on the learner's prior knowledge level, directly related to the number of interacting elements in the content being learned [3]. For example, when learning a complex task that requires multi-step coordination or a task with many unfamiliar terms and jargon, the learner's intrinsic cognitive load is high.

(2) Extraneous cognitive load: This load is caused by poor instructional design or inefficient presentation of learning materials. It is unrelated to the learning task itself and interferes with the learner's understanding of the core content, representing useless mental effort that hinders learning or task performance [4]. For example, redundant information, unnecessary visual elements, or confusing explanations can all increase extraneous cognitive load.

(3) Germane cognitive load: This load is a useful cognitive load related to the construction of knowledge schemas, and it is the core driving force for learners' deep learning. It encourages learners to actively understand and integrate new information, connect it with known information, and form coherent long-term memory schemas, thereby achieving deeper learning [1].

### 2.2. Analysis of cognitive load sources in Advanced Mathematics learning
### 2.2.1. Intrinsic cognitive load in Advanced Mathematics learning

The intrinsic cognitive load of advanced mathematics courses primarily stems from the abstractness of their concepts, the rigor of their logical structures, and the complexity of their problem-solving steps. Advanced mathematics centers on abstract mathematical concepts, along with extensive formula derivations, theorem proofs, and logical reasoning, which demand high levels of logical thinking and mathematical foundation from students. At the same time, students' prior knowledge level also determines the intrinsic cognitive load. Most vocational and technical education students lack interest in mathematics learning and awareness of autonomous learning in middle school. They are accustomed to passively receiving knowledge, not good at active thinking and exploration, which leads to a relatively weak mathematical foundation for these students. The complexity

of advanced mathematics and students' weak mathematical foundation lead to a high intrinsic cognitive load in advanced mathematics learning.

### 2.2.2. Extraneous cognitive load in Advanced Mathematics learning

The extraneous cognitive load of advanced mathematics courses originates from the instructor's instructional design and resource presentation methods. The knowledge system of advanced mathematics courses is highly rigorous, and concepts and formulas are strongly interconnected, requiring students to integrate fragmented knowledge into a knowledge system, which implicitly increases the difficulty of understanding. At the same time, abstract symbols, redundant text, and unnecessary images in advanced mathematics textbooks will increase irrelevant cognitive load and hinder learning. During course instruction, poor layout of multimedia courseware or blackboards, unclear charts, or overly complex language will increase the difficulty for students to understand relevant knowledge, thereby distracting them from the core content, leading to a high extraneous cognitive load in advanced mathematics learning.

### 2.2.3. Germane cognitive load in Advanced Mathematics learning

Germane cognitive load in advanced mathematics courses is reflected in the cognitive effort students invest when using mastered knowledge to memorize, understand, and apply new knowledge, or when using mathematical thinking and knowledge to analyze and solve problems. On the one hand, the use of effective teaching methods and tools, such as visualization tools, in advanced mathematics instruction directly affects the efficiency and quality of students' knowledge schema construction [5]; on the other hand, germane cognitive load is related to students' learning motivation. Students who are more interested in advanced mathematics often find learning easier than those who are not. Learning motivation is related to teachers' teaching methods, textbook updates, assessment methods, personal values, and the integration of ideological and political elements with professional and national strategies [6].

## 3. Learning strategies for Advanced Mathematics based on cognitive load theory

The core principle of Cognitive Load Theory is that the sum of intrinsic cognitive load, extraneous cognitive load, and germane cognitive load equals the total cognitive load. When the total cognitive load exceeds the limited capacity of working memory, the three types of cognitive load will compete for resources, and the student's brain cognition will be overloaded, thereby affecting the efficiency and quality of cognitive activities. To achieve more efficient learning outcomes, learning strategies can be adjusted to optimize the allocation of cognitive resources during the learning process, that is, within the limited capacity of working memory, by controlling intrinsic cognitive load, reducing extraneous cognitive load, and enhancing germane cognitive load to improve the efficiency and quality of cognitive activities [6].

### 3.1. Strategies for controlling intrinsic cognitive load
### 3.1.1. Tiered instruction

Adopt methods such as diagnostic tests to divide students into basic, consolidation, and advanced groups based on their knowledge levels, providing learning materials and tasks of different difficulties. Basic group students only learn relevant basic knowledge, focusing on formula derivations and complete practice of typical examples to ensure mastery of basic concepts; consolidation group students, after mastering basic knowledge, appropriately

increase the difficulty, adding variant problems and comprehensive problems after typical examples to improve their ability to flexibly apply mathematical knowledge; advanced group students should fully utilize their cognitive resources to achieve a deep understanding of knowledge, setting comprehensive application problems across chapters and concepts to cultivate innovative thinking. Tiered instruction, through reasonable learning material design, ensures that students at different levels receive training corresponding to their cognitive levels, avoiding situations of being "underfed" or "overfed," thereby achieving effective control of intrinsic cognitive load.

### 3.1.2. Knowledge deconstruction

Many theorems and problem-solving methods in advanced mathematics involve the comprehensive application of multiple steps and concepts. When learning, complex knowledge points can be broken down into easy-to-understand modules and taught in stages. For example, for integral calculation, one can start with basic integral formulas, first using direct integration, transforming the integrand, skillfully using techniques such as splitting, combining, and trigonometric transformations, and then gradually introducing methods such as substitution, a second type of substitution, and integration by parts. Deconstructing the complex knowledge system of advanced mathematics guides students from simple to difficult, tackling them one by one. This learning method helps students gradually build a knowledge system, avoiding exposure to too much knowledge at once, which can increase intrinsic cognitive load and lead to fear and aversion to learning.

### 3.1.3. Scaffolding learning

To help vocational and technical education students with weak foundations achieve higher learning outcomes, scaffolding can be built throughout the learning process, connecting the current learning content with known materials and building a bridge between teaching and learning. Create simulated scenario scaffolding, by creating activity scenarios to stimulate students' active participation, guiding students to think, find answers, and internalize knowledge in realistic situations; build dynamic progressive problem scaffolding, based on Vygotsky's Zone of Proximal Development theory, by designing a step-by-step problem chain to gradually guide students to think and help students acquire knowledge through meaning construction; build exemplary scaffolding, through carefully designed and arranged by teachers, providing exemplary learning scaffolding to stimulate students' learning enthusiasm and motivation, helping students understand and construct knowledge; build display platform scaffolding, using the display platform to help students "take small steps," progressing layer by layer, reducing frustration and stimulating self-efficacy; build interactive evaluation scaffolding, through various forms of process evaluation such as teacher evaluation, group evaluation, and online instant evaluation, to promote learning through evaluation[7].

## 3.2. Strategies for reducing extraneous cognitive load
### 3.2.1. Optimized instructional design

Advanced mathematics teaching should focus on core concepts and mathematical ideas. Teaching should be guided by key concepts, while also incorporating mathematical thinking such as functions and mappings, reduction and transformation, and the combination of numbers and shapes, to cultivate students' problem-solving abilities. Courseware design should highlight key points, reduce the extraneous cognitive load of students switching between different information sources, present tedious derivations as supplementary materials, display necessary formula derivations step by step, and remove background noise and irrelevant visual elements to

ensure students focus on core content. Optimize teaching structure and design, reasonably select teaching content, and for non-mathematics majors, content that is less applied or too difficult can be appropriately streamlined, using modular teaching to adapt to different professional needs. Adopt visualization and other presentation methods, using relevant intelligent equipment for dynamic demonstrations. For example, in the study of limits, instead of using traditional epsilon-delta language, concrete examples of limits approaching can be visualized with GeoGebra, Mathematica, MATLAB, etc., and supplemented with explanations to enhance students' intuitive understanding of the concept of limits, using concise, standardized, and popularized language.

### 3.2.2. Enhance interest-driven learning

Adopt case-driven and problem-oriented strategies to create vivid and interesting problem situations, introducing examples related to students' majors to reduce their unfamiliarity with abstract concepts. Professional contextualization: For example, when explaining the concept of derivatives to medical students, in addition to classic examples, medical-related examples such as drug absorption rates can be added; when explaining calculus concepts to vehicle maintenance students, it can be combined with engine power curves and fuel consumption models, making the learning content more professional and applicable through familiar professional backgrounds. Life contextualization: Introduce functions and limits through daily consumption, sports, and fitness scenarios, allowing students to experience the practicality of mathematics in familiar situations, which helps to concretize abstract concepts and reduce the difficulty of understanding.

### 3.2.3. Cultivate learning habits

Cultivating good learning habits and establishing a clear learning process can effectively reduce the interference of irrelevant information, thereby reducing extraneous cognitive load. Students preview relevant chapters of textbooks before class, try to understand relevant concepts and formulas, and at the same time sort out the difficulties encountered during their preview, forming personalized learning goals, thereby improving the efficiency of receiving information in class and being able to think purposefully during lectures. Students actively think in class, focusing on the difficulties encountered during the preview for targeted learning and understanding, rather than passively accepting theoretical knowledge and problem-solving techniques. Students, according to their actual situation, spend appropriate time each day reviewing what they have learned, then conduct post-class reviews, organize wrong questions, and analyze the causes of errors, forming a "knowledge-error-improvement-knowledge" closed loop.

### 3.3. Strategies for enhancing germane cognitive load

### 3.3.1. Consolidation and expansion

Establish a mechanism for reviewing wrong questions, guiding students to categorize wrong questions by knowledge points, record error reasons and correct thinking, analyze knowledge gaps, and review regularly. Establish a mechanism for variant training, encouraging students to practice variations of the same concept and problem to deepen their understanding of knowledge and cultivate their transfer ability. Create contextualized expansion content, stimulating students' desire for exploration through discussions of mathematical history, the intersection of mathematics and cutting-edge technology, and the combination of mathematics and professional contexts, prompting students to consolidate and expand their learned knowledge. Encourage students to connect abstract concepts with practical applications to build a broader knowledge network, which helps form richer and more flexible knowledge schemas. For example, when explaining the application of calculus in engineering,

breakthroughs in aerospace and artificial intelligence in China can be introduced to illustrate the key role of mathematical tools in solving practical problems, guiding students to understand the needs of a technology-innovative country.

### 3.3.2. Collaborative learning

Establish mutual learning groups, create opportunities for discussion and feedback, and encourage students to discuss complex mathematical problems or proof processes through collaborative learning and mutual exchange, jointly exploring solutions. Regularly organize sharing sessions where different groups share solutions to key and difficult points and problem-solving techniques, thereby effectively promoting the generation of germane cognitive load. For students with weak foundations, encourage group members to restate concepts in their own words to understand and apply knowledge, stimulating ideas in communication, inspiring each other, and jointly constructing knowledge schemas. Encourage peer teaching, pairing students with strong mathematical foundations with those with weak foundations to form a "teaching-learning" dual promotion. In the "teaching" process, students with strong foundations need to organize and explain knowledge, which is a deep processing of knowledge; in the "learning" process, students with weak foundations can gain a deeper understanding of relevant content through questioning and discussion. Establish a check-in and mini-quiz mechanism, implement resource sharing, and compile quality resources collected by each group to provide materials for further deep learning.

### 3.3.3. Evaluation and feedback

Establish a diversified evaluation mechanism, combining "daily assignments + stage tests + task completion" to enrich formative evaluation, explore personalized evaluation, and strengthen summative evaluation. Formative evaluation is based on the growth patterns and professional needs of vocational and technical education students, incorporating mathematical literacy, critical thinking, professional application, and teamwork into the assessment scope, focusing on learning process performance and task completion quality. Personalized evaluation methods include using knowledge graph platforms to obtain student learning profiles accurately, and using smart teaching platform backend data to intuitively analyze student learning trajectories, recording the completion of pre-class previews, classroom teaching, and after-class assignments to generate personalized learning reports. Task-based projects based on group cooperation can also be added to enhance the assessment of students' collaboration skills and comprehensive application abilities. Balance important knowledge points in stage tests, reduce calculation load, and appropriately increase application problems or modeling problems with practical backgrounds to address the problem of emphasizing knowledge over ability and weakening education.

# 4. Conclusion and outlook

## 4.1. Conclusion

This paper, based on Cognitive Load Theory, proposes systematic learning strategies for vocational and technical education students facing difficulties in advanced mathematics learning. Overall, the learning strategies for advanced mathematics based on Cognitive Load Theory can control intrinsic cognitive load through tiered instruction, knowledge deconstruction, and scaffolding learning; reduce extraneous cognitive load through optimized instructional design, enhanced interest-driven learning, and cultivation of learning habits; and enhance germane cognitive load through consolidation and expansion, collaborative learning, and evaluation

and feedback. Through these learning strategies, the learning efficiency and quality of advanced mathematics for vocational and technical education students will be effectively improved.

## 4.2. Outlook

Future research and practice can be further deepened in the following aspects:

(1) Develop Personalized and Intelligent Learning Systems: With the rapid development of artificial intelligence, personalized intelligent learning systems based on Cognitive Load Theory can be developed. This system can monitor students' learning status in real-time, dynamically adjust teaching content, difficulty, and presentation methods based on the monitoring results of students' cognitive load levels, thereby helping students adjust their learning methods. For example, when the system detects that a student's extraneous cognitive load is too high, it can simplify the presentation of teaching content; when the system detects that a student's intrinsic cognitive load is too high, it can help the student refine knowledge points and break down current learning tasks.

(2) Promote Teacher Professional Development through Technology Empowerment: The effective application of Cognitive Load Theory is inseparable from the improvement of teachers' professional literacy. Leveraging opportunities for professional backbone teacher training, train teachers on how to understand and apply Cognitive Load Theory to optimize instructional design and classroom management. Utilize modern technologies, such as virtual reality (VR) and augmented reality (AR), to provide teachers with richer teaching tools and create more immersive and interactive teaching environments, more effectively stimulating students' germane cognitive load.

(3) Construct a Multi-Theory Integrated Teaching Model: Deeply integrate Cognitive Load Theory with other cognitive theories such as Piaget's theory of cognitive development, Perry's theory of cognitive growth stages, and APOS theory (Action-Process-Object-Schema). By constructing a multi-dimensional, more comprehensive teaching model, gain a deeper understanding of students' cognitive characteristics at different developmental stages, and then, through specific teaching methods, help students learn advanced mathematics knowledge and cultivate their autonomous learning ability.

## Disclosure statement

The authors declare no conflict of interest.

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