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Article

Signal and system inspiration based on classroom teaching

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Abstract: Signals and Systems is a core foundational course in electronic information - related majors. Its abstract nature, mathematical intensity, and conceptual depth pose significant challenges to both teaching and learning. Based on classroom teaching practices and reflections, this paper conducts an in - depth analysis of the major cognitive barriers students encounters during the learning process. It proposes a novel teaching and cognition framework centered on "concept concretization", "structured thinking" and "situational knowledge application". By integrating specific teaching strategies and practical cases, the paper explores how to effectively build a bridge between theory and application. This approach promotes the development of students' higher - order thinking skills and engineering practice awareness, ultimately enhancing the overall teaching effectiveness of the course.

Keywords: signal and system; teaching cognition; the concretization of the concept; structured thinking; contextualization of knowledge; engineering thinking

1. Introduction

The “Signals and Systems” course serves as a crucial link between foundational courses like circuit analysis and advanced topics such as digital signal processing, communication principles, and automatic control. Its core aim is to guide students in mastering the theories and methods of signal analysis (in time, frequency, and complex frequency domains) and system characterization (via differential/difference equations, impulse responses, system functions, and block diagrams), as well as understanding their interconnections and engineering significance (Basseville, 1988; Kwakernaak et al., 1991; Lee, 2011). However, teaching practice reveals several cognitive challenges:

1) Highly Abstract Nature: Signals, as information - carrying physical quantity functions, and systems, as entities that transform or process signals, are inherently abstract concepts. Core tools like the Fourier, Laplace, and Z - transforms are based on complex mathematical foundations such as complex - variable functions.

2) Mathematical Intensity: The course content is deeply intertwined with advanced mathematical knowledge, including calculus, linear algebra, differential equations, and complex - variable functions. Students often get lost in complex mathematical derivations and lose sight of the physical concepts and engineering context.

3) Complex Conceptual Relationships: Analysis methods in time, frequency, and complex frequency domains (s - domain and z - domain) have distinct characteristics yet are interconnected. The fundamental properties of linear time - invariant (LTI) systems run throughout the course, and students struggle to form a clear and unified knowledge framework.

4) Disconnection Between Theory and Application: Students frequently question the purpose and application of the theories they learn and find it difficult to apply abstract theories to concrete engineering problems such as filtering, modulation, sampling, and control system design. This leads to a lack of motivation and clear learning objectives (Ghavami et al., 2007; Portnoff, 1980).

The root of these problems lies in students’ insufficient understanding of core concepts, low structuring of knowledge systems, and the disconnect between theory and engineering practice. Therefore, updating teaching cognition and exploring effective teaching strategies are key to improving teaching quality.

2. The core dimension of teaching cognition: deconstructing learning disabilities

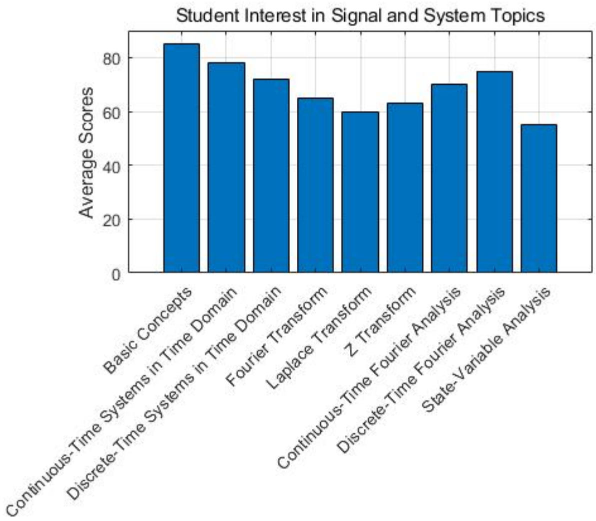
Based on analyses of the student learning process and teaching feedback, the core teaching cognition of this course focuses on three interconnected dimensions:

1) Concept Visualization & Concretization: Students find it hard to imagine abstract mathematical operations (e.g., convolution integrals, spectrum shifting) and physical concepts (e.g., frequency responses, system stability). Abstract concepts must be transformed into tangible forms using visualization tools and physical analogies. For instance, animations can demonstrate the convolution process (flipping, shifting, multiplying, integrating). The filtering effects can be shown using audio and image signals. Spring - mass systems can analogize the time - domain response characteristics of second - order systems.

2) Thinking Structuring: Students need to establish a systematic analytical paradigm and clear mind maps. Emphasize the general process of “problem definition -> method selection (time domain Frequency domains - domain/z - domain) -> theoretical application -> result solving -> physical interpretation”. Reinforce the connections and comparisons between different analytical domains. For example, the Fourier transform is a special case of the Laplace transform on the imaginary axis. Weave fragmented knowledge points into a conceptual network (Wang et al., 2021). For example, explore the relationships between impulse responses, step responses, system functions, frequency responses, and poles/zeros and system properties.

Figure 1

Contents of each chapter of signal and system Students' learning interest histogram



3) Knowledge Contextualization: Students often feel that what they learn is "in the air" and cannot link formulas and theorems to the real engineering world, leading to a lack of intrinsic motivation. Theory must be anchored in specific engineering application scenarios (Wang et al., 2021; Zhu, 2017). For example, when teaching the sampling theorem, link it to CD audio and digital image processing; when teaching filter design, introduce channel selection in wireless communication and noise removal in biomedical signals; when teaching system stability, connect it to automatic control system design. Through case - based teaching, simplified projects (e.g., designing a simple audio equalizer concept) and simulation experiments (Matlab/Python), students can experience the process of "applying what they learn" and understand the engineering value of the theory.

As shown in **Figure 1**, overall, students show high interest in basic concepts and time - domain analysis in the "Signals and Systems" course. But their interest is relatively low in chapters involving complex mathematical transforms and advanced analysis methods, such as Fourier, Laplace, and Z - transforms as well as state - variable analysis (Wei, 2016; Liu, 2012). This indicates that in the teaching process, we need to adopt teaching strategies and methods according to the characteristics of different chapters to enhance students' interest and learning outcomes. For example, when explaining basic concepts, we can use vivid examples and intuitive demonstrations to deepen students' understanding. When interpreting complex transforms and analysis methods, we can incorporate more practical application cases and experimental activities (Hua, 2013; Meng et al., 2021; Yang et al., 2014; Yan, 2020). This helps students better understand and master the knowledge, thereby boosting their learning enthusiasm.

3. Teaching strategies and practice: building a cognitive bridge

As per the above - mentioned teaching cognition, a core strategy emphasizing intuitive cognition and physical - concept explanation will be systematically implemented in classroom teaching, experimental design, and assessment. Specifically, multimedia technologies will be fully utilized. designed PPT animations, interactive simulations on professional platforms (e.g., Matlab GUI, Simulink, Python libraries), and tailored short - video cases will dynamically present core abstract concepts. These include signal - transformation processes, system - response characteristics, and spectrum - analysis results, thereby enhancing students' sensory understanding.

When explaining system properties described by differential equations, typical physical - model instances like RLC circuits and mechanical vibration systems will be introduced. The analogy - teaching method will be used to establish a direct mapping relationship between system mathematical descriptions and their physical - behavior features. This deepens students' understanding of system essentials. Additionally, visual representation will be a basic teaching - process principle (Yang et al., 2015). Standard graphical expressions, including time - domain/frequency - domain waveform diagrams, spectrum graphs, system zero - pole distribution charts, system block diagrams, and signal flow graphs, will be used. These intuitively and clearly reveal intrinsic laws in signal - and - system analysis. Moreover, efforts will be made to build a structured knowledge system and mind maps.

The "Framework - First" strategy requires that at the start of each chapter or module, the knowledge be clearly located within the curriculum. Core teaching goals and analytical methods must be defined, and links to previous and subsequent knowledge explained, helping students build a global knowledge framework (Yang and Feng, 2016). The "Contrast - and - Summarize" strategy is used in key modules (such as time - domain analysis, Fourier analysis, Laplace/Z - transform analysis). Through carefully designed tables or mind maps, students are guided to compare different analytical methods. This includes looking at their applicability, main problem - solving targets, and their strengths and limitations. This deepens students' understanding of method - selection criteria.

The problem - oriented teaching strategy is reflected in the teaching design. Representative, progressive problem chains are designed. Students are guided to follow a structured analysis process. This includes identifying the nature of a problem, selecting analytical methods, applying theoretical foundations, solving models, and explaining physical meanings. Particular-emphasis is placed on guiding students to think critically about method selection at key decision - making points.

The concept - map tool application strategy aims to promote knowledge integration. Students are encouraged and guided to use concept - map tools to visually represent core concepts such as “signals”, “systems”, “transforms”, and “properties” and their complex inter - relationships. This reveals the inherent logical structure of the knowledge network and strengthens systematic understanding.

In case - driven teaching, theoretical knowledge is integrated into carefully selected small - scale engineering practice cases. For example, Fourier - transform theory explains the principle of guitar - string chord composition and its link to timbre. System - function analysis methods explore the causes and suppression of potential nonlinear distortion in audio amplifiers. Z - transform and difference - equation theory enables the initial design of a simple digital filter.

The simulation - experiment - based cognition - deepening phase goes beyond simple theoretical verification. It focuses on exploration and design - oriented practice. Students quantitatively observe the effects of different window functions on spectral leakage in a simulation environment. They actively adjust the zero - pole distribution of systems to explore its impact on frequency - response characteristics. They also complete a full simulation chain of a signal modulation and demodulation process.

The experiment requires not only obtaining simulation results but also rigorously explaining their physical mechanisms and analyzing their engineering applications and design insights. Simplified engineering projects are introduced. Students conduct small - scale investigative topics, such as “Spectral Analysis and Design of Simple Mobile Phone Ringtones” or “Preliminary Exploration of Power - Frequency Interference Suppression in Simulated ECG Signals”. They go through a complete miniaturized engineering practice process. This includes user - requirement analysis, technical - scheme design, tool selection, simulation - model construction, result evaluation, and optimization. The aim is to cultivate students’ systematic engineering thinking and problem - solving skills.

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Industry experts and cutting - edge applications are introduced at the right time. Engineers from related fields are invited for specialized lectures or demonstrations. They focus on the latest breakthroughs and typical application cases of signal - processing technology in key areas such as communication systems, radar detection, medical imaging, and artificial intelligence. This effectively broadens students' academic and engineering horizons and stimulates their strong interest and intrinsic motivation in exploring the frontiers of the discipline.

4. Teaching effect and reflection

After implementing the teaching strategies based on the core cognitive framework of "concept visualization", "structured thinking" and "knowledge contextualization", several positive changes were observed in the teaching practice. Students' interest was significantly enhanced, as they established a more concrete perception of abstract mathematical formulas, finding them "visible" and "tangible". Their understanding of the learning objectives became clearer, and classroom participation and interaction deepened. The depth of understanding of core concepts was notably improved. In homework, discussions and exams, students accurately grasped the physical meaning of key concepts, such as spectrum characteristics and system functions, reducing formula - application without considering physical context.

Students' analytical abilities became more structured. When facing new problems, they systematically selected analysis methods based on problem characteristics, such as time - domain, frequency - domain or transform - domain approaches. They tried to explain results by combining physical mechanisms and engineering backgrounds, showing initial signs of structured thinking. Awareness of engineering practice began to emerge. Through case analysis and project practice, students recognized the value of signal - system theories in engineering applications. Their modeling and analysis skills were exercised, laying a solid foundation for future studies and practice.

Despite these positive changes, several challenges emerged during implementation. Balancing the depth and breadth of teaching is a key challenge. Within limited class hours, it is challenging to finely design and allocate the rigor of mathematical foundations, in - depth exploration of core concepts, and extensive coverage of engineering applications. The demand for differentiated instruction has become increasingly prominent. Given students' differences in mathematical foundations, cognitive styles, and learning objectives, there is an urgent need to develop more personalized learning - support plans. For instance, teachers could design tiered tasks and provide extended learning resources.

As shown in **Table 1**， keeping teaching cases and projects up - to - date presents a continuous challenge. Teachers need to closely follow the latest developments in signal - processing technologies across cutting - edge fields like artificial intelligence, the Internet of Things, and biomedical engineering. They must constantly update the case library and project topics to maintain the course's appeal and relevance. Reforming the assessment system is imperative. The focus should be on restructuring evaluation methods, including final exams and project reports. This will enable more effective assessment of students' abilities in concept understanding, structured thinking, and engineering - application awareness, moving beyond mere calculation - skill assessment (Morawski, 2007; Parhi, 2021; Zoltowski,1996).

Table 1

Quantitative statistical difficulty of signal and system chapters

section	Common knowledge points	Difficulty coefficient (1-5)
Basic Concepts of Signals and Systems	Definition and classification of signals, definition and classification of systems, basic properties	1
Time domain analysis of continuous-time systems	Differential equation solution, zero input response, zero state response, impulse response, step response	3
Time domain analysis of discrete-time systems	Difference equation solution, unit sequence response, recursive method	3
Fourier transform	The properties of CTFT, DTFT, Fourier transform and Fourier transform of common signals.	4
Laplace transformation	Convergence domain, properties, system function, pole-zero distribution, stability	4
Z-transform	Convergence domain, properties, system function, pole-zero distribution, stability	4
Fourier analysis of continuous-time systems	Filtering, modulation and demodulation	3
Fourier analysis of discrete-time systems	Frequency response, digital filter	3
State variable analysis	State equation, output equation, matrix operation, system performance analysis	5

5. Conclusion and Foresight

The successful implementation of the “Signals and Systems” course hinges on transcending mere mathematical - formula enumeration and isolated problem - solving - skill instruction. It requires delving into students’ cognitive - construction processes. By systematically advancing concept visualization to resolve abstract - theory comprehension barriers, enhancing structured thinking to build the internal logical framework of knowledge systems, and deepening knowledge contextualization to establish organic links between theoretical principles and engineering practice, an effective core - competence bridge can be built. This bridge connects mathematical foundations, physical essences, and engineering applications.

Future curriculum - reform efforts will focus on three dimensions: Concrete - visualization - deepening: exploring VR and AR technologies for dynamic visualization of key concepts like signal time - frequency properties and system response behaviors.

Structured - tool optimization: developing integrated intelligent knowledge - graph platforms and adaptive learning - path recommendation systems. This supports dynamic construction and optimization of students’ personalized knowledge systems.

Contextualization - boundary expansion: strengthening ties with cutting - edge interdisciplinary fields such as AI, biomedical engineering, and the Internet of Things. This involves designing more challenging and comprehensive real - world application cases and project tasks.

Only by continuously focusing on students’ cognitive - development laws, closely tracking engineering - technology trends, and deeply integrating modern educational technologies can the classic “Signals and Systems” course maintain its vitality. This approach will effectively cultivate a new generation of electronic - information professionals with solid mathematical foundations, clear systematic thinking, and keen engineering practice literacy.

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