

# THEORETICAL FOUNDATIONS OF COMPETENCY INTERFERENCE IN COGNITIVE-NEURODIDACTIC- COMPETENCY-INTEGRATIVE EDUCATIONAL MODEL

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## **Abstract:**

The integration of cognitive, neuropsychological, and competency-based approaches in the Cognitive-Neurodidactic-Competency-Integrative (CNCI) educational model presents significant challenges when phases and competencies are not properly aligned. This study analyzes competency interference phenomena that occur when universal human competencies (UHC), personal competencies (PC), general professional competencies (GPC), and professional competencies (PRC) are organized in a discordant manner. Through analysis of cognitive load theory (CLT), dual coding theory (DCT), and brain-based learning (BBL) frameworks, we identify four primary types of interference: functional, methodological, sequential, and load interference. Our findings demonstrate that cognitive phase misalignment, unmanaged cognitive loads, and contextual detachment significantly impair learning outcomes in engineering education. We propose systematic solutions including phase-based competency alignment, balanced cognitive load distribution, and interdisciplinary integration strategies. This research provides theoretical foundations and practical frameworks for optimizing competency-based curricula in technical education.

**Keywords:** Competency interference, CNCI model, cognitive load theory, engineering education, cognitive phases, competency-based learning.

## **Introduction**

The integration of cognitive, neuropsychological, and competency-based approaches has become a critical issue in the global education system (Sweller, 2011; Mayer, 2021). Specifically, in engineering and technical education, there is a growing need to restructure educational content in accordance with phases of cognitive development (Streveler & Smith, 2006). The contemporary challenges in professional education necessitate updating traditional

taxonomies of educational goals to better align with modern learning requirements (Olimov, Alimov, Bezgodova, & Musayeva, 2025). This requirement is being implemented through the Cognitive-Neurodidactic-Competency-Integrative (CNKI) education model, which aligns phases and competencies based on CEFR cognitive levels (A1–C2), Bloom's taxonomy (Anderson & Krathwohl, 2001), Cognitive Load Theory (Sweller, Van Merriënboer, & Paas, 2019), Dual Coding Theory (Paivio, 2006), and Brain-Based Learning (Caine & Caine, 1991). When phases and competencies are not properly aligned in the educational process, interference situations arise that reduce cognitive impact, decrease motivation, and hinder deep mastery of knowledge (Kirschner, Sweller, & Clark, 2006; Van Merriënboer & Sweller, 2005). Despite the recognized importance of competency-based education, there is limited systematic analysis of how different types of competencies interact and potentially interfere with each other during the learning process (Frank et al., 2010).

This study aims to: (1) identify and classify types of competency interference in the CNKI model, (2) analyze the theoretical foundations of interference from CLT, DCT, and BBL perspectives, (3) examine cognitive phase interference and its manifestations, and (4) propose evidence-based solutions to mitigate interference effects in engineering education.

### **Theoretical Framework**

Competency interference is defined as the confusion, mutual obstruction, or lack of development that occurs in the educational process when universal human competencies (UHC), personal competencies (PC), general professional competencies (GPC), and professional competencies (PRC) are organized in a discordant manner. This phenomenon manifests when competencies compete for cognitive resources, contradict each other functionally, or are presented in inappropriate sequences (Mulder, 2014; Weinert, 2001).

Cognitive Load Theory identifies three types of cognitive load: intrinsic (complexity of content), extraneous (inefficient presentation), and germane (effort to integrate with prior knowledge) (Sweller et al., 2019; Chandler & Sweller, 1991). Learning often proceeds through stages of cognitive development—from initial exposure through integration to transformation (Chi & Wylie, 2014). If instruction bypasses or scrambles these phases, learners cannot effectively build required schemas (Kalyuga, 2007). CLT demonstrates that instruction must titrate intrinsic load to the developmental stage of the learner, with beginners requiring worked examples and limited tasks, while advanced learners need open-ended integration tasks (Renkl, 2014; Van Gog & Rummel, 2010).

Dual Coding Theory emphasizes the importance of aligning verbal and visual coding systems in learning (Paivio, 2006; Clark & Paivio, 1991). Brain-Based Learning principles suggest that when different competency types activate simultaneously in the brain without proper coordination, neural activity becomes uncertain and learning efficiency decreases (Caine & Caine, 1991; Jensen, 2008). These frameworks provide essential foundations for understanding how competency interference occurs at neurological and cognitive processing levels.

## **Methodology**

This study employs a theoretical analysis methodology combined with systematic literature review to examine competency interference in the CNCI model (Torraco, 2005). We analyzed the structural relationships between different competency types and cognitive phases, identifying points of potential interference through framework analysis of CLT, DCT, and BBL principles (Jabareen, 2009).

The analysis framework consisted of four dimensions: (1) competency type interactions (UHC, PC, GPC, PRC), (2) cognitive phase progressions (Transformation, Integration, Metamorphosis, Structuring, Optimization, Conceptualization, Generalization, Metacognition), (3) cognitive load distribution patterns, and (4) instructional design factors. Each dimension was examined for potential interference points where misalignment could impair learning outcomes (Miles & Huberman, 1994).

Interference types were classified based on their functional characteristics and manifestation patterns. We systematically analyzed: (1) how one competency might suppress or contradict another (functional interference), (2) whether formation methods align with competency objectives (methodological interference), (3) the appropriateness of competency sequencing (sequential interference), and (4) cognitive load distribution compatibility (load interference) (Strauss & Corbin, 1998).

Literature review focused on empirical studies in engineering education, particularly cases involving problem-based learning, cognitive load management, and competency-based curriculum design (Cooper, 1998). Evidence was synthesized to identify documented instances of interference effects and successful mitigation strategies. Special attention was given to studies demonstrating phase misalignment effects and cognitive overload in technical education contexts (Streveler et al., 2008; Prince, 2004).

## **Types of Competency Interference**

Our analysis identified four distinct types of competency interference in the CNCI model, each with characteristic manifestations and impacts on learning outcomes.

<b>Interference Type</b>	<b>Definition</b>	<b>Examples</b>
Functional Interference	One competency suppresses or contradicts another	Personal critical thinking skills negatively affect professional decision-making when applied inappropriately
Methodological Interference	Methods for forming competencies do not align with their objectives	Personal initiative becomes automatic activity without reflection when taught through rote procedures
Sequential Interference	Occurs when competencies are formed non-sequentially without proper developmental connection	Moving to technical skills without establishing foundational universal human values
Load Interference	From CLT perspective—cognitive loads are distributed incompatibly	Simultaneously loading UHC and PRC skills causes cognitive stress and confusion in students

### **Competency Interference Points**

Analysis revealed specific intersection points where competency types are most likely to interfere with each other, along with their causal mechanisms and evidence-based solutions.

<b>Intersection Point</b>	<b>Potential Interference</b>	<b>Cause</b>	<b>Solution</b>
UHC ↔ PC	Moral principles and personal empathy misalignment	Not separating spiritual concepts from personal needs	Ethical case studies, developmental debates
PC ↔ GPC	Contradiction between independence and teamwork	Student is active in individual tasks but passive in groups	Role distribution within groups, structured cases
GPC ↔ PRC	General theoretical knowledge and practical ability misalignment	Scientific theory separated from practice	Modeling, simulation, active laboratories
UHC ↔ PRC	Practical experience without values	Technical solutions without ethical approach	Ethical projects, social discussion elements

### **Cognitive Theory Perspectives on Interference**

From the perspectives of CLT, DCT, and BBL, competency interference manifests through distinct cognitive mechanisms, each requiring specific interventional approaches.

<b>Theory</b>	<b>Interference Manifestation</b>	<b>Solution</b>
CLT	When extraneous load is added to germane load, working memory capacity is exceeded	Separate competencies by phase, balance necessary loads through scaffolding
DCT	When verbal and visual codes are incorrectly aligned, dual processing is disrupted	UHC visual; PRC technical-verbal; PC audio-cases; GPC with diagrams and infographics
BBL	When different competency types activate simultaneously, neural activity becomes distributed and inefficient	Organize phase-adapted, contextual and functional activity system with sequential activation

### **Cognitive Phase Interference**

Phase interference occurs when the eight cognitive phases of the CNCI model (Transformation, Integration, Metamorphosis, Structuring, Optimization, Conceptualization, Generalization, Metacognition) experience misalignment in functions, cognitive tasks, or educational content.

Phase Transition	Interference Type	Description
Transformation → Integration	Early practical load	Forcing practical activities before basic concepts are formed causes schema disruption and confusion
Integration → Metamorphosis	Reflectionless action	Moving to personal transformation without analysis prevents deep understanding and metacognitive development
Structuring → Optimization	Premature optimization	Optimizing processes before structure is solidified disrupts systematic thinking and problem-solving
Conceptualization → Generalization	Weak abstraction	Generalizing before concepts solidify prevents effective knowledge transfer to new contexts

### **Cognitive Load Distribution Patterns**

Evidence from engineering education demonstrates clear patterns of how different load types impact learning outcomes when competencies interfere (Sweller et al., 2019; Young et al., 2014).

Load Type	Source	Effect if Unmanaged
Intrinsic	Core difficulty of the task/material	If too high, learners become overwhelmed; novices struggle to process essential elements (Sweller et al., 2019)
Extraneous	Clarity and alignment of material presentation	Arises from unclear instructions or irrelevant information; distracts learners and wastes working memory (Chandler & Sweller, 1991)
Germane	Effort to construct or automate schemas	Productive load for learning, but insufficient working memory remains if intrinsic/extraneous loads are excessive (Kalyuga, 2007)

### **Discussion**

The identification of four distinct types of competency interference demonstrates that competency misalignment operates through multiple mechanisms. Functional interference reveals how competencies can actively suppress each other, while methodological interference shows that inappropriate teaching methods can transform intended competencies into unintended outcomes (Mulder, 2014). Sequential interference highlights the critical importance

of developmental progression (Gagné, 1985), and load interference underscores cognitive capacity limitations in simultaneous competency development (Sweller et al., 2019).

The specific intersection points identified between competency types (UHC↔PC, PC↔GPC, GPC↔PRC, UHC↔PRC) represent predictable vulnerabilities in competency-based curricula. Each intersection point exhibits characteristic interference patterns with identifiable causes, suggesting that systematic prevention is possible through targeted instructional design.

In competency-based engineering education, mismanaged cognitive load is well-documented. Studies of first-year engineering students using problem-based learning found that without clear guidance, students could not map real-world problems onto mathematical models (Jonassen, Strobel, & Lee, 2006). They lacked the schema to make sense of the situation, so complex tasks led them off-task. In effect, intrinsic load was too high for their developmental phase, and germane processing was blocked, causing frustration and task abandonment (Kirschner et al., 2006).

This evidence supports the load interference concept: when multiple competencies simultaneously demand cognitive resources without proper scaffolding, learning efficiency degrades dramatically (Van Merriënboer & Sweller, 2005). The three-load framework (intrinsic, extraneous, germane) provides clear diagnostic criteria for identifying when and why competency interference occurs at the cognitive processing level.

The analysis of cognitive phase interference reveals that transitions between phases represent critical vulnerability points. The jump from Transformation to Integration (early practical load) and from Integration to Metamorphosis (reflectionless action) are particularly problematic because they involve qualitative shifts in cognitive processing requirements (Chi & Wylie, 2014). When instruction forces premature phase transitions, learners cannot develop the prerequisite schemas needed for the next phase, creating cascading deficits throughout subsequent learning.

Case studies demonstrate this vividly: engineering students asked to design bridges before mastering statics failed not due to lack of effort but because the phase mismatch prevented coherent mental model formation (Turns, Atman, & Adams, 2000). The abstract design task required integration and structuring phases that could not occur without completed transformation phase foundations.

Evidence from the literature suggests multiple effective strategies for mitigating competency interference. Well-designed competency courses embed scaffolding strategies including worked examples, stepwise fading of support, and segmentation of complex projects to reduce extraneous load and pace intrinsic load appropriately (Renkl, 2014; Van Gog & Rummel, 2010). The key principle is matching instructional demands to learners' current developmental phase while systematically building toward more complex integration.

The solutions identified at competency intersection points—ethical case studies for UHC↔PC conflicts, role distribution for PC↔GPC tensions, modeling and simulation for GPC↔PRC gaps—all share common features: they provide structured bridges between competency domains, explicitly address potential conflicts, and create opportunities for integrated

application rather than isolated skill development (Prince, 2004; Kolmos, Fink, & Krogh, 2004).

This study extends cognitive load theory by demonstrating how competency types themselves can be sources of intrinsic and extraneous load when improperly sequenced or combined. The competency interference framework integrates CLT with competency-based education theory (Frank et al., 2010), providing a unified explanation for why well-designed individual competencies can still produce poor learning outcomes when combined without careful consideration of cognitive constraints.

From a dual coding theory perspective, the findings emphasize the importance of matching encoding modalities to competency types (Paivio, 2006; Mayer, 2021). Universal human competencies benefit from visual presentation, professional competencies from technical-verbal explanations, personal competencies from audio cases, and general professional competencies from diagrams and infographics. This differentiation prevents coding system conflicts that can create extraneous cognitive load.

The practical implications for curriculum design are substantial. Engineering and technical education programs should:

1. Map all competency intersection points and proactively design bridging activities
2. Sequence competency development according to cognitive phase requirements
3. Monitor cognitive load distribution through formative assessment
4. Employ phase-appropriate scaffolding that fades systematically as learners progress
5. Use varied encoding modalities matched to specific competency types

This study's primary limitation is its theoretical-analytical approach. While grounded in established cognitive science principles and supported by case study evidence, direct empirical validation of the competency interference framework is needed. Future research should include controlled experiments manipulating competency sequencing and measuring learning outcomes (Cook & Campbell, 1979), as well as longitudinal studies tracking students through entire curricula to identify where interference effects emerge over time.

Additionally, the framework's applicability across different disciplines and educational levels requires investigation. While developed in engineering education context, the principles may transfer to medical education (Harden, 2002), business education, and other professional training domains. Cross-cultural validation is also important, as competency interference patterns may vary with different educational traditions and cultural learning preferences.

## **Conclusions**

Competency interference in the CNCI model represents one of the most critical cognitive challenges in modern competency-based education. The systematic identification of four interference types (functional, methodological, sequential, and load), specific intersection points between competency domains, and phase transition vulnerabilities provides a comprehensive framework for understanding and addressing these challenges.

The integration of Cognitive Load Theory (Sweller et al., 2019), Dual Coding Theory (Paivio, 2006), and Brain-Based Learning principles (Caine & Caine, 1991) demonstrates that

competency interference operates through well-understood cognitive mechanisms. This theoretical grounding enables evidence-based solutions: phase-based competency alignment, balanced cognitive load distribution, modality-matched instruction, and interdisciplinary integration.

For practitioners, the key insight is that competency-based education requires more than listing competencies—it demands careful orchestration of when and how competencies are introduced, practiced, and integrated. Cognitive science provides clear principles for this orchestration (Bransford, Brown, & Cocking, 2000), and ignoring these principles leads to predictable interference patterns that undermine learning. The competency interference framework offers both diagnostic tools for identifying problems and prescriptive guidance for prevention and remediation.

Ultimately, optimizing competency-based education requires recognizing that the human cognitive system has inherent processing constraints and developmental sequences. Successful curriculum design works within these constraints rather than against them, creating learning environments where competencies develop synergistically rather than interfere destructively. The CNCI model, properly implemented with attention to interference mitigation, offers a promising framework for achieving this goal in engineering and technical education.

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