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Article

Evolutionary-Theoretical Analysis of Key Concept-Based Teaching Technology in Higher Technical Educational Institutions

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Abstract: This article investigates the challenges of optimizing students' cognitive load and systematizing the educational process amid the rapid surge of information volume in higher technical educational institutions. As a viable solution, a methodology centered on keywords is proposed. Using the subject "Automotive Design" as a case study, keywords are analyzed as tools for cognitive visualization, data compression, and as metrics for formative assessment. The study mathematically and didactically models John Sweller's Cognitive Load Theory, providing a scientific framework for mechanisms aimed at minimizing extraneous load and enhancing the efficiency of the Return on Investment (ROI) in education.

Keywords: Cognitive Load Theory, Working Memory, Scaffolding, Data Compression, Human Capital, Real-Time Formative Monitoring

1. Introduction

It is widely acknowledged that the global landscape of engineering education and the higher education ecosystem of our republic are currently experiencing a rapid and intensive surge in the volume of scientific and technical information. This expansion necessitates a thorough transformation of the methodological framework and the didactic architecture of the instructional process. In disciplines exploring complex technical systems, sub-assemblies, and kinematic chains—such as "Automotive Design"—the sheer density of data often conflicts functionally with the natural capacity of students to process information. Under these circumstances, the proposed approach of working with keywords serves as a foundational instrument for the cognitive systematization of instructional material and the alignment of student thinking with engineering models. Within the framework of this model, the educational process has been successfully transformed from traditional static lectures into an "Inverted Classroom" (Flipped Classroom) technology [1].

From a theoretical pedagogical perspective, the Uzbek scholar U.I. Inoyatov characterizes a keyword as an educational unit that encapsulates the most critical function

of the technical object or process under study; it generates a logical code within the student's memory to systematically reconstruct intricate structural components [2].

Furthermore, R.G. Safarova emphasizes that a keyword-based teaching technology optimizes the student's cognitive load by leveraging structural systematization devices. Within this process, each keyword manifests as a cognitive model of a specific technical configuration, thereby helping the student construct a holistic view of the system's overarching architecture [3].

The Law of the Republic of Uzbekistan "On Education" establishes the advancement of the intellectual and scientific proficiency of learners and the integration of independent thinking mechanisms as sustainable directions of state policy, which directly demands the development of qualified personnel capable of driving industrial efficiency. Similarly, research by the Russian scholar O.N. Oleynikova demonstrates that keywords function as primary cognitive instruments that safeguard a student's professional adaptability; they map out the future engineer's terminological field and establish the theoretical-practical foundation of professional competence [4].

Information systematization based on keywords enhances instructional efficiency by minimizing time waste and cognitive losses throughout the learning loop. This methodology transitions the student from a passive consumer of information into an active subject who cognitively models their own knowledge. Such an approach aligns seamlessly with the tasks outlined in Decree No. PF-37 of the President of the Republic of Uzbekistan dated February 21, 2024, which mandates "aligning the quality of higher education with labor market requirements and strengthening practical orientation" [5].

Within the structural approach to educational quality management put forward by U.I. Inoyatov and R.X. Jo‘rayev, keywords act not merely as instructional aids, but as objective indicators for real-time formative assessment [6].

Additionally, as demonstrated in the research of J.Z. Madaminov, proficiency in handling key concepts serves as the methodological cornerstone for developing the graphical and design-oriented competencies of engineering personnel. Consequently, the theoretical foundations of keyword-based teaching technology rest upon a synthesis of cognitive psychology, didactic systematization, and the economics of human capital [7].

Literature Review

Within the scope of this study, the cognitive-methodological functions of keywords in engineering education and their efficiency criteria were analyzed across three primary methodological schools:

The L.V. Zankov School

The Method of Cognitive Data Archiving and Compression

The defining characteristic of technical disciplines lies in the multi-component nature of their systems and the complex interdependencies among them. In the course "Automotive Design," students encounter an overwhelming flow of data regarding the intricate configurations of mechanical components and their kinematic relationships [8]. In this scenario, keywords assume the function of a cognitive "code" or "archiver." By anchoring key concepts such as "body," "steering mechanism," or "braking system" within the student’s memory, the operational algorithm of the entire system is structurally preserved. This process relies on the principle of cognitive data compression, drastically accelerating the retrieval speed of information when needed [9].

The "archiving" function is theoretically supported by L.V. Zankov’s theory of developmental education, which asserts that instructional material should be presented at a high level of difficulty but must anchored by logical prompts. In "Automotive Design," keywords serve as "cognitive hooks" to structurally retain intricate kinematic linkages (e.g., driveshaft assemblies or differential mechanisms) within the student’s mind [10].

The J. Sweller School

The Method of Cognitive Load Optimization and Didactic Modeling

John Sweller’s Cognitive Load Theory acts as the psychophysiological basis for the keyword-driven formative assessment methodology. This theory is built upon the premise

that human working memory capacity is strictly limited, and it provides pathways to optimize the instructional process. Complex engineering blueprints and technical calculations can rapidly saturate a student's working memory. In this context, keywords function as a "scaffolding" technology, breaking down elaborate processes into compact, manageable, and technically descriptive units [11].

J. Sweller bifurcates human memory into two functional dimensions:

1. *Working Memory:* Where the immediate reception and active processing of information occur, characterized by highly restricted capacity and duration.
2. *Long-term Memory:* Where information is systematically organized and stored in the form of cognitive schemas, boasting unlimited capacity.

According to Sweller's theory, the total cognitive load (CL) imposed during the learning process is a combined function of three core components, expressed through the following conditional formula:

$$CL=IL+EL+GL$$

Where:

- IL (*Intrinsic Load*): The inherent complexity of the topic itself. For instance, studying the operating principle of a torque converter is inherently complex and cannot be altered, though the information can be segmented into smaller parts (*chunks*) using keywords.
- EL (*Extraneous Load*): The unnecessary mental burden caused by poor presentation or methodological ambiguities. If a lesson is cluttered with redundant details, the student experiences cognitive fatigue. Using keywords as formative indicators systematically eliminates this excess load.
- GL (*Germane Load*): The "beneficial" mental energy expended on constructing schemas and transferring information into long-term memory. The primary task of the instructor is to reduce extraneous load (EL) while maximizing germane load (GL) [12].

2. Methodology

In the context of "Automotive Design," if a structured system of keywords is omitted, the extraneous load (EL) escalates dramatically, occupying the bulk of the total working memory capacity (CL). As a result, no cognitive resources remain for the germane load (GL), inducing a state of cognitive blockade. Keywords counteract this by acting as cognitive scaffolding to minimize EL. Because each keyword acts as a retrieval code for a complex technical schema stored in long-term memory, the working memory can effortlessly process massive arrays of information as unified blocks (*chunks*).

The O.N. Oleynikova School

The Competency-Based Approach and Professional Flexibility Method

According to O.N. Oleynikova’s research within the framework of Competency-Based Education (CBE) in vocational and engineering tracks, keywords form the core of the future engineer's professional "terminological field". Professional flexibility is defined as a technician's capacity to seamlessly adapt and apply their knowledge to entirely new production scenarios within a rapidly shifting technological environment.

When a student learns to analyze a technical system through a hierarchy of key concepts, they acquire a foundational "mental map." This cognitive framework enables them to independently and rapidly diagnose the design of any modern transport vehicle. In our research, Oleynikova's approach is expanded by transforming keywords from mere elements of rote memorization into foundational metrics (units of measurement) for real-time formative assessment, serving as a didactic barometer for professional competence.

3. Results

Through theoretical-methodological research and cognitive analysis, the structural role, core functions, and anticipated didactic effects of keyword-based teaching technology within educational and professional systems have been systematized, Table 1.

System (Direction)	Scholar and Core Theory	Primary Approach and Core Idea	Anticipated Outcome (Case of "Automotive Design")
Information Archiving Mechanism	L.V.Zankov (Developmental Education Theory)	Delivering material at an advanced difficulty level while anchoring it via logical "supports."	Muhrling complex kinematic chains within memory as integrated cognitive blocks (schemas).
Cognitive Load Reduction	J.Sweller (Cognitive Load Theory)	Reducing redundant extraneous load (EL) in working memory to maximize space for germane energy (GL).	Preventing mental exhaustion when mastering technical blueprints and intricate calculations.
Professional Adaptability	O.N.Oleynikova (Competency-Based Approach)	Shaping keywords into the professional "terminological field" of the future engineer.	Accelerating the structural analysis of modern vehicle designs, producing market-competitive personnel.

Within this research paradigm, a dynamic didactic algorithm model has been developed and deployed for the course "Automotive Design." This model successfully transitions the student from a passive listener into an active subject. The algorithm encompasses stages for the systemic acquisition of trilingual equivalents of keywords across every instructional segment (Macro, Meso, and Micro levels) and integrates them visually with dynamic animations [13].

4. Discussion

The compiled data reveals that keywords are far more than simple didactic materials; they operate as three fundamental criteria governing efficiency in engineering pedagogy:

1. Methodological Synthesis: L.V. Zankov's concept of the "intellectual ladder" has been operationalized in this study as a real-time indicator for formative assessment. Measuring how accurately a student applies keywords across various instructional segments yields a direct, quantifiable evaluation of their cognitive development.
2. Economic Efficiency and Human Capital (ROI): Interpreting John Sweller's Cognitive Load Theory through an economic lens demonstrates that minimizing instructional time waste (EL) effectively lowers the net cost of human capital development. In alignment with the human capital theories of Gary Becker and Theodore Schultz, saving cognitive resources accelerates the rate of information acquisition. In economic terms, this manifests as a reduction in the unit cost of educational delivery alongside an increase in the volume of knowledge acquired per unit of time [14].
3. Indicator-Based Assessment: Expanding upon O.N. Oleynikova's theory, utilizing keywords as formative metrics—rather than simple items to be memorized—effectively eliminates information gaps in the classroom. Because students use digital LMS platforms to familiarize themselves with key codes before class, a fully realized "Flipped Classroom" environment is successfully maintained [15].

5. Conclusions

Based on the analysis of the instructional methodology of "Automotive Design" within the "Transport Vehicle Engineering" specialization, and the evaluation of student competencies through cognitive-didactic frameworks, the following scientific-methodological conclusions have been established:

Information Balance and Cognitive Coding: Under conditions marked by exceptionally high structural density and spatial-kinematic complexity in "Automotive Design," traditional text-heavy teaching models routinely trigger information chaos

among students. In this environment, keywords function as a highly effective cognitive code, facilitating systemic data compression and enabling the swift activation of complex technical schemas within long-term memory during live instruction.

Didactic Optimization of Cognitive Load: Mathematical-didactic modeling based on Sweller's formula (CL=IL+EL+GL) demonstrates that anchoring the lesson design with a matrix of keywords minimizes extraneous load (EL) caused by methodological ambiguities. Consequently, the cognitive resources saved within working memory are channeled into schema construction, triggering a measurable increase in useful germane energy (GL).

Subject Status and Regulatory Alignment: Elevating keywords from basic vocabulary items into functional metrics for real-time formative assessment fundamentally reforms the student's educational status. The system shifts the learner from a passive recipient of information (an object) into an active subject who independently solves complex engineering and diagnostic problems in real time. This transformation fulfills the strategic mandates outlined in Presidential Decrees PF-37 and PF-58, which demand the calibration of human capital with market requirements through continuous formative monitoring.

Recommendations

To optimize the efficiency of the educational process across higher engineering institutions, the following practical recommendations are advanced:

- Semantic Modification of Curricula: Review and update existing syllabi and course curricula for "Automotive Design" to mandate the inclusion of a key concept hierarchy—alongside their trilingual (Uzbek/Russian/English) terminological equivalents—across Macro, Meso, and Micro levels for every topic.
- Digitalizing the Flipped Classroom Model via LMS: Build specialized digital didactic modules within institutional learning management systems (HEMIS/Moodle) to provide students with 3D dynamic animations and engineering-graphical models synchronized with keywords for independent study prior to classroom sessions.
- Transformation of Assessment Criteria: Shift engineering departments away from delayed, static summative testing at the end of semesters. Instead, widely implement real-time formative diagnostics during lectures and practical labs to continuously measure students' visual-kinematic literacy using keyword indicators.

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