Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 03 , March - 2026

# Neurocognitive instructional design applying bionic learning principles in Sub Saharan African technical and vocational education

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Abstract - Technical and Vocational Education and Training (TVET) systems are under increasing pressure to deliver instruction that aligns with the dynamic nature of human cognition, yet learners frequently experience cognitive overload regarding abstract technical concepts. This study explores the integra-tion of "bionics of learning"—a biomimetic instructional design approach—within the Don Bosco Tech Africa (DBTA) network to address this gap. Utilizing a mixed-methods design, primary data was collected from TVET instructors and learners ($N = 109$) across Kenya, Nigeria, and Ghana. Quantitative analysis of learner cognitive engagement revealed strong positive correlations between multi-sensory instruction and spaced repetition ($r = 0.68$), as well as chunking and sustained engage-ment ($r = 0.58$). Furthermore, Natural Language Processing (NLP) of qualitative data highlighted a severe pedagogical dichotomy, wherein abstract theoretical instruction induced cognitive overload, whereas embodied, practical execution facilitated robust memory encoding. These findings advocate for a paradigm shift from static, transmission-based curricula to neuro-adaptive, bio-inspired learning environments that mimic the adaptive feedback loops found in natural biological systems.

**Keywords:** Bionic Learning, Cognitive Load Theory, TVET, Neuro-adaptive Instruction, Biomimicry, Educational Neuroscience.

## 1. Introduction

The digital transformation of education has ac-celerated the integration of technology into learn-ing environments, offering unprecedented access and scalability. However, contemporary instruc-tional systems in Technical and Vocational Ed-ucation and Training (TVET) frequently remain rigid and predominantly content-driven. These traditional frameworks often fail to account for the dynamic, embodied, and adaptive nature of human cognition and memory processing (Sousa, 2016).

In Sub-Saharan Africa, TVET programs play a critical role in addressing youth unemploy-ment and bridging the skills mismatch in the 21st-century labor market. Organizations such as Don Bosco Tech Africa (DBTA), which coor-dinates over 110 TVET institutions across the Africa-Madagascar region, serve as vital hubs for technical skill acquisition. Despite institutional strengths in hands-on training and values educa-tion, current curriculum designs often lack sys-tematic alignment with cognitive neuroscience principles. Consequently, learners report difficul-ties in sustaining focus, retaining key skills, and transferring theoretical knowledge to practical execution.

Biological organisms exhibit remarkable learn-ing abilities through mechanisms such as sen-sory integration, real-time feedback loops, adap-tation, and self-regulation. This phenomenon has catalyzed interest in the "bionics of learn-ing"—an approach that borrows adaptive prin-ciples from biology to optimize instructional de-sign. This study aims to evaluate the align-ment between current TVET instructional prac-tices and cognitive neuroscience, providing an evidence-based framework for integrating neuro-adaptive, biomimetic strategies into African tech-nical education.

## 2. Literature Review

The theoretical foundation of this study relies on the intersection of biological sciences, cogni-tive psychology, and instructional design. This section reviews literature relevant to bionic learn-ing, establishing how biologically inspired sys-tems and adaptive technologies inform next-generation learning environments.

### 2.1. Bionics and Bio-mimicry in Instructional Design

The philosophical divergence between bionics and bio-mimicry significantly influences instruc-tional design in technical education. Bionics em-phasizes the application of biological functions to enhance human systems, often through mechani-cal or digital replication. In educational technol-ogy, this manifests as neuro-adaptive learning

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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systems that dynamically adjust content based on learners' attention and engagement patterns (Najafabadi et al., 2021). These systems lever-age artificial intelligence and feedback loops to augment learning in complex technical fields.

Conversely, bio-mimicry seeks sustainable integration with nature. As argued by Capra & Henderson (2009), bio-mimicry aims to learn from nature to design inherently regenerative systems. In pedagogy, this ethos translates to environments that co-evolve with learners. Benyus (1997) defined the bio-mimicry approach through three tenets: nature as a model, nature as a measure, and nature as a mentor. Middendorf (2021) advocated for bio-mimicry as a model for participatory and ethical design in education.

### 2.2. Theoretical Foundations: Cognition and Pedagogy

The goals of bionic learning align closely with foundational pedagogical theories, such as Piaget's constructivism and Kolb's experiential learning theory, which emphasize active, contextual learning (Kolb, 1984). Furthermore, Sweller's Cognitive Load Theory (Sweller, 1994) is paramount in neuro-adaptive design. It high-lights the biological necessity of reducing extra-neous cognitive load to optimize working mem-ory capacity. Immordino-Yang (2015) expanded on this by emphasizing the role of emotion in cognition, arguing that meaningful learning is neurologically dependent on emotional process-ing.

In the context of DBTA, these principles synchronize seamlessly with Salesian pedagogy. The *Preventive System*, developed by St. John Bosco, promotes holistic education by focusing on emotional well-being, relational teaching, and practi-cal skill acquisition (Stella, 2007).

### 2.3. Neuro-adaptive Learning Systems

Advances in affective computing and neurofeedback demonstrate the potential for real-time detection of learner cognitive states using devices like EEG headsets or eye-trackers (D'Mello & Graesser, 2012). Neuro-ergonomics explores how to optimize the fit between cognitive sys-tems and technology, serving as a foundational pillar for designing bionic learning environments (Parasuraman & Rizzo, 2007). Empirical studies, such as Zhao et al. (2021), have demonstrated improved retention and reduced cognitive overload when learners receive feedback based on real-time biological signals.

### 2.4. Gaps in Literature

There is limited research on neuroscience-informed instructional design in African TVET. DBTA presents an untapped opportunity for test-ing and scaling such innovations.

The existing literature highlights several key limitations in current research on adaptive and neuro-informed learning systems:

- Most adaptive learning technologies are built on algorithmic personalization (e.g., recommender systems or learner modeling) rather than grounded in real-time biological or cognitive signals.

- Studies involvinge motion-aware or brain responsive systems are typically conducted in laboratory settings or high-resource con-texts, making their findings difficult to apply to low-resource, hands-on learning environments such as TVET centers in Africa.

- There is limited research on how neuro-cognitive principles - such as attention modulation, memory encoding, and feedback cy-cles - can be embedded into practical voca-tional training, particularly in diverse, mul-tilingual, and resource-constrained environ-ments like those found at Don Bosco Tech Africa (DBTA).

- The concept of bionic learning environments, inspired by biological systems and informed by cognitive neuroscience, remains largely underdeveloped in applied educational con-texts, especially in African TVET institu-tions.

### 2.5. Research Approach to Address Gaps

To address the above gaps, this study proposed a mixed-methods research strategy that integrated cognitive neuroscience with practical instructional design in TVET contexts. The approach:

- Applied bio-mimetic principles to instructional design by mirroring how biological systems learn—using techniques such as feedback loops, spaced repetition, multi-sensory input, and chunking to support deeper learning.

International Journal of Engineering Research & Technology (IJERT)
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- Introduced nents—such as EEG headbands, attention tracking, or engagement logging (where feasible)—to explore the cognitive and emotional responses of learners in real time, enhancing instructional feedback.
- Used primary data (from surveys, inter-views, and classroom observations) col-lected in selected Don Bosco Tech Africa cen-ters (in Kenya, Ghana, and Nigeria) to evalu-ate the alignment between current teaching practices and neuroscience-informed design principles.
- Developed a tested instructional framework, grounded in both qualitative insights and quantitative evidence, that could guide the future integration of bionics-inspired learn-ing models across similar African vocational education systems.

### 2.6. Summary

This review highlighted the growing interest in biologically inspired, neuroadaptive learning systems. While foundational theories support the need for adaptive and emotionally engaging learning, the application of bionic principles in real-world TVET settings remained limited. This study addressed these gaps by combining bio-mimicry, neuroscience, and instructional design to build learning environments that respond to the learner as dynamically as biological systems do.

## 3. Materials and Methods

This study employed a mixed-methods qualita-tive and quantitative research design. The sam-pling frame consisted of TVET learners ($N = 109$) and technical instructors purposively se-lected from DBTA centers actively implementing competency-based training in Kenya, Ghana, and Nigeria. Represented disciplines included ICT, Electrical Installation, Welding, and Mechanical Engineering.

Data collection instruments included struc-tured Likert-scale questionnaires (1 = Strongly Disagree to 5 = Strongly Agree) assessing instruc-tional perception, cognitive workload, and en-gagement. Quantitative data underwent descrip-tive and correlational statistical analysis using Python-based data science environments. Quali-tative open-ended responses from learners and instructors were transcribed and parsed utilizing Natural Language Processing (NLP) to extract lexical frequencies and thematic codes regarding pedagogical practices and cognitive bottlenecks.

## 4. Results

### 4.1. Instructor Pedagogical Paradigms

Analysis of the instructor cohort revealed a ro-bust intuitive command of cognitive load man-agement. Instructors predominantly utilized heuristic chunking, restricting information de-livery to limit cognitive burden. Furthermore, over half of the surveyed educators reported ac-tively utilizing bio-inspired analogies to teach abstract concepts. Examples included comparing computer networks to the human cardiovascu-lar system or contextualizing software optimiza-tion algorithms via the foraging behavior of ant colonies.

When queried on desired technological inter-ventions, educators uniformly requested real-time, data-driven adaptive systems, such as "Cognitive Load Monitors," capable of quantify-ing learner overwhelm to eliminate pedagogical ambiguity.

### 4.2. Learner Cognitive Engagement

Descriptive statistical analysis of the learner co-hort ($N = 109$) quantified baseline instructional perceptions across core neuro-pedagogical prin-ciples (Table 1).

Table 1: Descriptive Statistics for Learner Cogni-tive Perception

| Instructional Variable | Mean ($M$) | Std. Dev ($SD$) |
|---|---|---|
| Spaced Repetition | 3.99 | 1.11 |
| Chunking | 3.90 | 1.12 |
| Multi-Sensory Input | 3.79 | 1.32 |
| Engagement | 3.75 | 1.20 |
| Feedback Loops | 3.63 | 1.15 |
| Cognitive Load (Pacing) | 3.31 | 1.21 |

While Spaced Repetition and Chunking scored highly, *Cognitive Load* (measuring adequate prac-tice time before new topic introduction) yielded the lowest positive mean, coupled with a high standard deviation ($SD = 1.21$). This variance in-dicated that instructional pacing frequently out-stripped the working memory capacity of a sig-nificant portion of the cohort.

International Journal of Engineering Research & Technology (IJERT)
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### 4.3. Correlational Analysis

A Pearson correlation matrix identified highly significant statistical relationships between applied cognitive principles. The strongest correlation existed between *Multi-Sensory Input* and *Spaced Repetition* ($r = 0.68$), indicating that instructors who conducted cyclical reviews were highly likely to execute them using tactile, hands-on methods. Additionally, *Chunking* and *Engagement* exhibited a strong positive correlation ($r = 0.58$), providing quantitative substantiation that modular segmentation of instructional steps directly preserves a learner's capacity to sustain focus.

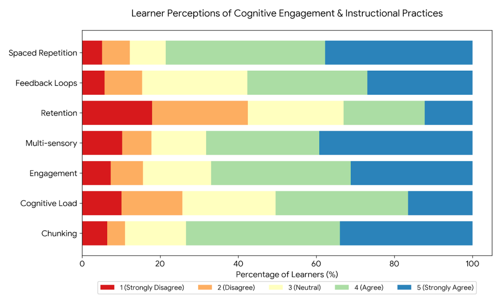


Figure 1: Pearson Correlation Matrix of Applied Cognitive Principles

### 4.4. NLP and Qualitative Bottlenecks

Keyword frequency extraction from learner narratives overwhelmingly highlighted a pedagog-ical dichotomy. The lexical token "practical" emerged as the most frequently utilized term ($f = 32$), sharply juxtaposed against the term "theory" ($f = 17$). Learners universally cited abstract symbolic representations—specifically mathematical "formulas" and "detailed trou-bleshooting procedures"—as the most difficult content to retain.

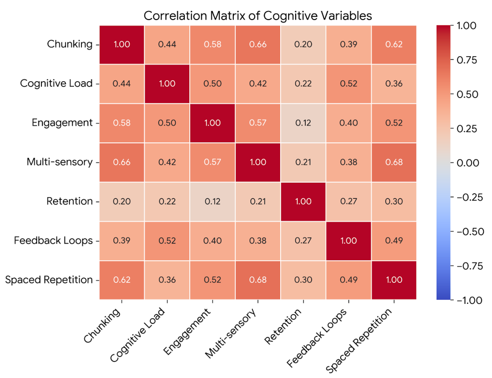


Figure 2: Lexical Token Frequencies from Learner Narratives

## 5. Discussion

The synthesis of empirical data confirms the necessity of transitioning toward a neuro-adaptive instructional model in Sub-Saharan TVET systems. The identified "Theory-Practice Dichotomy" illustrates a profound cognitive bottleneck: while learners efficiently encode phys-ical skills through biomimetic mimicry and em-bodied practice, abstract theoretical instruction rapidly induces cognitive overload.

The NLP analysis corroborates that abstract technical theory, when isolated from tactile manipulation, fails to securely anchor in long-term memory. The strong correlational data ($r = 0.68$) between multisensory input and successful spaced repetition suggests that review sessions are optimized when they involve whole-body, experiential execution rather than passive auditory recall.

To bridge this gap, instructional design must mimic the efficiency of biological systems. Just as organisms adapt dynamically to environmental stimuli, educational frameworks must feature real-time, adaptive feedback loops, dynamically compressing theoretical exposition in favor of immediate, iterative practical execution.

## 6. Conclusions

This study establishes that integrating the "bion-ics of learning" into African TVET systems offers a highly effective, neurologically aligned path-way to improving technical education. Tradi-tional, static curriculum delivery actively con-flicts with the biological constraints of human working memory. To optimize skill acquisition, institutions must prioritize embodied cognition, severely reduce uninterrupted theoretical lec-tures, and embrace neuro-adaptive methodolo-gies that provide real-time cognitive scaffold-ing. Future research should focus on prototyping AI-driven adaptive learning environments capa-ble of scaling these biomimetic principles across resource-constrained educational networks.

### Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Institutional Ethics Review Committee of Don Bosco Tech Africa (DBTA).

**Informed Consent Statement**

Informed consent for participation was obtained from all subjects involved in the study.

**Data Availability Statement**

The datasets used and/or analyzed during the current study are available from the correspond-ing author on reasonable request.

**Author Contributions**

Conceptualization, Methodology, Formal Analy-sis, Investigation, Resources, Data Curation, Writ-ing – Original Draft Preparation, Writing – Re-view & Editing, Visualization, Project Adminis-tration: F.M.M. The author has read and agreed to the published version of the manuscript.

**Funding**

This research received no external funding.

**Conflicts of Interest**

The author declares no conflict of interest.

**References**

Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature*. Harper Perennial.

Capra, F., & Henderson, D. (2009). *The systems view of life: A unifying vision*. Center for Ecoliteracy.

D'Mello, S., & Graesser, A. (2012). AutoTutor and affective autotutor: Learning by talking with cognitively and emotionally intelligent com-puters that talk back. ACM Transactions on In-teractive Intelligent Systems, 2(4), 1â€“39.

Immordino-Yang, M. H. (2015). *Emotions, learning, and the brain: Exploring the educational implications of affective neuroscience. W. W. Norton & Company.*

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development. Prentice-Hall.*

Middendorf, B. J. (2021). Designing with nature: Rethinking education through biomimicry. Journal of Educational Innovation, 12(2), 45–59.

Najafabadi, M. M., Hassan, M. S., & Mustapha, A. (2021). Neuroadaptive systems and their applications in personalized learning: A review. *Computers & Education*, 165, 104147.

Parasuraman, R., & Rizzo, M. (2007). *Neuroergonomics: The brain at work*. Oxford University Press.

Sousa, D. A. (2016). *How the brain learns* (5th ed.). Corwin Press.

Stella, J. (2007). *Preventive system and Salesian pedagogy*. Don Bosco Press.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, 4(4), 295–312.

Zhao, Q., Liu, Y., & Yang, J. (2021). EEG-based adaptive learning system for real-time cogni-tive load management. *Computers & Education*, 165, 104154.