The dual-track teaching practice of design discipline driven by neuroscience under the orientation of innovative talent cultivation

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Abstract: In response to the pain points of traditional design education such as the dominance of "visual centrism", subjective evaluation, and insufficient cross-domain innovation capabilities, this study takes the cultivation of innovative talents as the orientation and constructs a design discipline teaching model of "neuroscience-driven + dual-track collaboration". The traditional skills consolidation track focuses on the cultivation of basic abilities such as modeling and materials. Neural perception empowerment (devices like EEG and fNIRS) collects biological signals such as electromyography and skin temperature from learners, and combines algorithms to map biological data into multimodal design parameters (such as haptic feedback and odor interaction). Promote the transformation of design discipline teaching from "one-way knowledge transmission" to an innovative talent cultivation model featuring a two-way cycle of "perception - cognition - creation". Empirical evidence shows that this model significantly enhances students' metacognitive monitoring ability (reducing decision-making time by 52% and increasing prefrontal lobe activation efficiency by 37%), cross-domain integration effectiveness (increasing the output of cross-border solutions by 2.1 times and enhancing γ -wave coherence by 0.68), and emotional empathy accuracy (extending user stay time by 2.4 times and achieving a mirror neuron synchronization rate of 0.73). The effectiveness of the dual-track teaching driven by neuroscience in cultivating innovative talents has been verified, providing a replicable practical path for the transformation of design education from "experience-oriented" to "science-enabled".

1. Introduction

1.1 The Practical Predicament of Traditional Design Education

The essence of design education lies in cultivating creative problem-solving abilities, but the traditional curriculum model has three core contradictions:

Firstly, "visual centrism" leads to the simplification of the dimension of perception. The current courses overly focus on visual expression while neglecting the cultivation of multi-sensory synesthesia abilities such as touch and hearing. Research shows that 83% of design students take visual observation as their main source of inspiration, and their scores in non-visual perception ability tests are only 61% of those of the general population. This single perception mode severely restricts the divergence of innovative thinking. Secondly, teaching evaluation relies on subjective experience and lacks objective quantitative basis. Traditional evaluation mainly relies on teachers' subjective judgment of the completeness and aesthetic value of the plan (accounting for more than 70%), making it difficult for students to recognize the growth trajectory of their own decision-making logic and knowledge integration ability. Data shows that the creative potential scores of the same group of students vary by 35% among different teachers, indicating a significant lack of credibility in the evaluation.

Thirdly, the cultivation of cross-domain innovation and emotional empathy capabilities lags behind. In the face of complex scenarios such as elderly-friendly design, students often lack interdisciplinary integration capabilities and user emotional insight, resulting in design solutions that are "technically feasible but emotionally disconnected". Enterprise research shows that only 28% of fresh graduates can independently complete the full-chain design from user needs to emotional experiences.

1.2 Teaching Transformation Mechanism driven by neuroscience

Breakthroughs in cognitive neuroscience have provided a new path to solve the above-mentioned predicament: on the one hand, brain imaging techniques (such as fNIRS and EEG) can capture the

cognitive state of learners in real time (such as metacognitive monitoring and brain region collaboration during concept integration); On the other hand, biological signal acquisition technologies (such as electromyography and skin temperature sensors) can transform implicit perceptual experiences into quantifiable physiological data (Picard, 2021). These technologies provide multi-dimensional assessment tools of "biological - behavioral - cognitive" for design education, promoting the shift of teaching from "experience-driven" to "science-driven".

Based on this, this study proposes a teaching model of "neuroscience-driven + dual-track collaboration", which consolidates the design foundation through the traditional skills track and empowers innovative thinking through the neuroperception track, exploring a new paradigm for cultivating innovative talents.

2. Theoretical Framework: The core logic of the dual-track teaching model

2.1 Theoretical Connotation of the Dual-track System

2.1.1 The goals and framework of the dual-track teaching model

The dual-track teaching model takes "innovative talent cultivation" as its core goal and builds two parallel tracks: the "traditional skills consolidation track" and the "neural perception empowerment track". (See Figure 1) The former focuses on the systematic cultivation of basic abilities in the design discipline, while the latter relies on cognitive neuroscience technology to make cognitive processes explicit and upgraded. Both form a collaborative mechanism through "neuro-behavioral data fusion", jointly supporting students' ability leap from "skill mastery" to "innovative practice".

2.1.2 Traditional skills solidify the track

The Traditional Skills Consolidation Track takes the cultivation of basic abilities in the design discipline as its core. Through systematic course modules (such as modeling language training, material and process practice, and full-process design operation), it helps students master the hard power of "design tools" proficiently. The key point lies in establishing a standardized technical framework - for instance, enhancing visual expression ability through sketching and color training, mastering material properties and processing techniques through wood/metal craft practice, and learning the complete chain from requirement analysis to model making through design processes. This track emphasizes "instrumentality" and "standardization", aiming to prevent students'

innovative potential from being restricted by technical shortcomings and lay a solid technical foundation for subsequent cross-domain innovation and complex problem-solving.

2.1.3 Neural perception Empowerment Track

The neural perception empowerment track is based on cognitive neuroscience and, through biological signal acquisition and multimodal feedback technology, transforms implicit cognitive processes such as metacognition and knowledge integration into quantifiable indicators. This system utilizes neural data to monitor cognitive states and converts them into design parameters through multimodal feedback such as touch and smell, helping students perceive their own cognitive processes and adjust their learning strategies, achieving a transformation from passive execution to active creation in the learning mode.

This track achieves deep collaboration with the traditional skill training track through "neuro-behavioral data fusion" : skill training provides practical scenarios for neural perception, while neural data offers optimization directions for skill training. This two-way interaction forms a complete closed loop of "skill acquisition → neural representation → ability advancement", providing a dual-wheel drive support mechanism for the cultivation of innovative talents.

2.2 Cognitive Foundation Driven by Neuroscience

This model is based on three major cognitive neuroscience theories:

2.2.1 Metacognitive monitoring theory:

Metacognition refers to an individual's ability to monitor and regulate their own cognitive processes, which includes three core links: planning, monitoring and reflection. Its neural basis is located in the prefrontal cortex, a brain region that dynamically regulates cognitive processes by integrating target information with real-time status.

The changes in the alpha wave power (8-12Hz) of the prefrontal lobe can be observed through electroencephalogram (EEG) technology: the higher the power, the stronger the cognitive inhibitory ability and the more concentrated the attention. This indicator provides a neurophysiological basis for the quantitative assessment of metacognitive ability.

In teaching applications, real-time monitoring of alpha wave power can accurately determine students' cognitive states. When the data changes significantly, teachers can provide targeted guidance to help students establish the connection between decision-making efficiency and neural activity, thereby effectively enhancing metacognitive ability.

2.2.2 Concept Integration Theory:

The concept integration theory reveals the cognitive mechanism of cross-domain knowledge fusion in the innovation process. This theory emphasizes that the essence of creative thinking lies in selectively combining and reconstructing information from different cognitive domains to form a conceptual structure with new characteristics. In the context of design education, this is reflected in the organic integration of multiple elements such as technical knowledge, user experience and aesthetic principles.

Neuroscience research indicates that this integration process relies on the collaborative working mechanism of multiple brain regions. When an individual integrates cross-disciplinary knowledge, different functional areas of the brain achieve information synchronization through high-frequency neural oscillations, forming a temporary neural workspace. The efficiency of this neural collaboration directly affects the smoothness of knowledge integration and the quality of innovative achievements. In teaching practice, students' ability to integrate concepts can be evaluated by monitoring neural activity signals. Based on these neural feedback data, teachers can design targeted interdisciplinary teaching strategies for students who need to be strengthened, enhance their neural synergy patterns through diverse knowledge stimulation, and ultimately promote the transformation of students' abilities from knowledge recipients to innovative integrators.

2.2.3 Affective Computing Theory:

The theory of affective computing focuses on identifying and responding to human emotions through technical means. Its core "empathy" ability requires designers to have a deep understanding of user needs. The neural basis of this ability lies in the mirror neuron system, which is activated and generates an empathetic experience when an individual observes others' emotional expressions.

The blood oxygen changes in the mirror neuron region can be monitored through fNIRS technology, thereby quantifying empathy ability. An increase in blood oxygen concentration that is synchronized with the user's mood indicates a strong ability to empathize, which provides an objective basis for evaluating the insight into user needs.

In teaching, based on neural feedback data, targeted training can be carried out, such as micro-expression recognition and emotional diaries, helping students shift from subjective speculation to neuroscience-driven demand insight, significantly enhancing empathy and design targeting.

3. Practical Approach: The specific implementation of dual-track teaching

3.1 Curriculum System Reconstruction: From "Single-track Skills" to "Dual-Track Collaboration"

Traditional design education evaluation centers on "scheme results", with teachers relying on subjective dimensions such as "visual completion" and "aesthetic value" for scoring (accounting for over 70%). This not only fails to reflect the dynamic process of students' ability growth but also makes it difficult to identify specific shortcomings. This model constructs a four-dimensional evaluation system of "process + result" and "behavior + nerve", achieving precise assessment of innovation capabilities through dual verification of behavioral data (external manifestations) and nerve indicators (internal physiological symptoms).

Taking the "Comprehensive Design Workshop" course of the Design college of a certain university as a pilot (2 credits, 16 weeks), the reconstructed curriculum system is as follows:

Course module	Traditional skills solidify the track	Neural perception empowerment track
Basic training	Modeling language (sketching, color, three-dimensional composition)	Introduction to Biological Signal Acquisition

	Materials and Processes (Wood/Metal)	(Used for electromyography sensors and skin temperature patches)
Project practice	Thematic creation (such as "Community Public facilities." "Design")	Cross-domain collaboration (involving psychology major students Complete the "Analysis of Elderly Users' Demands"
Feedback optimization	Teacher's Plan Review (Visual Dimension)	Multimodal feedback (tactile simulation of user operations) Experience +EEG monitoring decision-making takes time.
Exhibition of Achievements	Static Works Exhibition (Models, renderings)	Dynamic Experience Exhibition (combining scents and sounds A multi-sensory interactive device

This system transforms "innovation capability" into quantifiable indicators (such as α-wave power and γ-wave coherence), achieving three major breakthroughs: ① Accurately identifying shortcomings (such as insufficient integration of γ-wave low-pointing knowledge); ② Avoid the "result-oriented" approach and focus on the thinking process; ③ Dynamic feedback supports teaching optimization (for example, if the synchronization rate is low, empathy training will be pushed). It is not only an assessment tool but also an "optimization engine" for dual-track teaching, promoting the transformation of design education from "experience inheritance" to "scientific empowerment".

3.2 Teaching Tool Development: Biological Signal Acquisition and Multimodal Feedback System

Based on the theory of neural plasticity, we have developed the "Design Cognitive Perception System (DCPS)", which promotes the development of design cognitive ability through biological signal monitoring and multimodal feedback.

The system uses EEG to monitor the changes of alpha waves in the prefrontal lobe and evaluate the metacognitive state. fNIRS detects the blood oxygen level in the mirror neuron region to measure empathy ability. The multimodal feedback module converts physiological signals into design guidance: when the alpha wave power decreases (decision-making efficiency improves), haptic feedback is enhanced;

When empathy is enhanced, specific fragrances are triggered to strengthen user-oriented thinking.

The visualization platform generates a cognitive ability heat map, presenting the development trajectories in dimensions such as metacognition and concept integration, enabling students to clearly understand their ability weaknesses and achieve data-driven precise cultivation. This system combines neuroscience with design teaching, providing scientific support for the cultivation of innovative talents through quantitative cognition, real-time feedback and growth visualization.

3.3 Evaluation System Innovation: Quantitative Assessment of Behavioral and Neurological Dual Indicators

Traditional evaluation only focuses on "scheme results", while this model constructs a four-dimensional evaluation system of "process + result" and "behavior + nerve" (see Table 2). This table is the framework of the "Behavior-Neural dual-index Quantitative Evaluation System", focusing on three innovative dimensions: metacognitive monitoring, cross-domain integration, and emotional empathy. Each dimension includes behavioral indicators (explicit manifestations) and neural indicators (internal physiological symptoms), and assigns differentiated weights of 30% to 40% to achieve a four-dimensional evaluation of "process + result" and "behavior + neural".

Evaluation latitude	Behavioral indicators	Neural indicators	"Weight
Metacognitive monitoring	The number of iterations of the plan The rate of time reduction in decision-making	Alpha wave power of the prefrontal lobe	30%

ability		Decline rate （>20%）	
Cross-domain integration efficiency	The frequency of interdisciplinary knowledge invocation Degree of innovation of the solution	γ -wave coherence （>0.7）	40%
Emotional empathy precision	The duration of user stay Demand matching accuracy rate	Mirror neuron synchronization rate （>0.7）	30%

This system breaks through the traditional result-oriented evaluation. By linking behavioral (such as the number of iterations) with neural (such as alpha wave power) indicators, it makes implicit capabilities explicit. The weight focuses on innovative cores such as cross-domain integration (40%), providing data support for teaching optimization and promoting the transformation of evaluation from subjective experience to scientific empirical evidence.

4. Empirical Analysis: The Effectiveness of Innovative Talent Cultivation through Dual-track Teaching

4.1 Experimental Process

This study selected the 2022 undergraduate students (n=60) from the School of Design of a certain university as the research subjects and randomly divided them into the experimental group (dual-track teaching, n=30) and the control group (traditional teaching, n=30). The experimental period was 16 weeks. Data collection included:

• Behavioral data: Number of solution iterations, decision-making time consumption, output of cross-domain solutions, and user dwell time

• Neural data: Prefrontal alpha wave power, gamma wave coherence, mirror neuron synchronization rate (collected through the DCPS system)

• Qualitative data: Student interviews (n=30), enterprise mentor evaluations (n=10)

The students in the experimental group were significantly superior to those in the control group in multiple dimensions (p<0.01) : the number of scheme iterations increased by 42%, the decision-making time was reduced by 35%, the output of cross-domain schemes increased by 2.3 times, and the user stay time was extended by 68%. Neural data show that an increase in the power of alpha waves in the prefrontal lobe reflects a 37% improvement in metacognitive ability, a 58% increase in gamma wave coherence indicates an enhanced concept integration ability, and a 61% increase in the synchronization rate of mirror neurons proves an improvement in empathy ability.

Qualitative analysis shows that 87% of the students in the experimental group believe that neural feedback helps optimize the design plan. The enterprise mentors evaluated their works as "more innovative and user-oriented", with a score 1.8 points higher.

4.2 Experimental Conclusion

The dual-track teaching model is significantly superior to the traditional one in the core dimensions of innovative talent cultivation, verifying the effectiveness of "neuroscience-driven + dual-track collaboration".

4.2.1 Improvement in metacognitive monitoring capability: The number of iterations of the experimental group's scheme (5.3 times vs. The reduction rate of decision-making time (55% vs. 18% in the control group) was significantly higher (p<0.01), and the decrease rate of alpha wave power in the prefrontal lobe (27.5% vs. The control group (8%) indicates that the neural basis for students' "active optimization" is more solid.

4.2.2 Breakthrough in cross-domain integration efficiency: Frequency of cross-disciplinary knowledge invocation in the experimental group (11 times vs. The control group (3 times), the degree of scheme innovation (enterprise score 4.5 points vs. control group 2.8 points) were significantly improved (p<0.01), and the gamma wave coherence (0.92 vs. The control group (0.65) reached the threshold of "efficient knowledge integration" (>0.7), indicating that the multi-brain region collaborative model has been formed.

4.2.3 Enhanced emotional empathy accuracy: The duration of user stay in the experimental group (29 seconds vs. The accuracy of demand matching (4.6 points vs. 3.2 points of the control group) was significantly improved (p<0.01), and the synchronization rate of mirror neurons (0.82 vs. The control group (0.63) was higher than the "effective empathy" threshold (>0.7), indicating that the physiological basis for students to "put themselves in the users' shoes" has been established.

Research shows that the dual-track teaching approach enhances metacognition through neural feedback, promotes integrative thinking through multimodal training, and improves decision-making efficiency with real-time data guidance, effectively cultivating innovative design talents needed in the AIGC era.

5. Conclusions and Prospects

The "neuroscience-driven + dual-track collaborative" teaching model constructed in this study effectively addresses the issues of single perception, subjective evaluation, and insufficient cross-domain capabilities in traditional design education by strengthening the foundation through the traditional skills track and empowering innovation through the neuroperception track. Empirical data have verified the significant enhancement effect of this model on innovative core capabilities such as metacognitive monitoring, cross-domain integration, and emotional empathy, providing a replicable path for the transformation of design education from "experience-oriented" to "science-enabled".

Future research can be further expanded: First, explore the differences in the dual-track teaching system among different majors (such as industrial design and visual communication); The second is to develop personalized neurofeedback strategies in combination with AI technology (such as automatically pushing cross-border cases based on students' γ wave levels);

Third, establish a cross-school joint "neural design education" database to promote the standardization of the model. The practical value of this research lies in providing a reference for the educational reform of other creative disciplines such as engineering and art, and helping to cultivate innovative talents who can adapt to complex scenarios in the future.

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