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Research on Digital Twin Wisdom Teaching Mode for Cultivation of Higher-Order Thinking Skills

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Abstract

As global digital transformation of education continues to gain momentum, higher-order thinking skills have become an important dimension of the core competitiveness of talents. The traditional teaching paradigm is limited to specific liabilities of physical time and space, identified as well as a scarcity of resources, thereby limiting the support to the systematic cultivation of learning on students' critical thinking as courses of study, innovative design, and complex problem-solving capabilities linked to their education and professional development. Digital twin technology, defined as possessing a characteristics of virtual-real mapping, dynamic simulation and real-time feedback, provides a new avenue for ushering in a reconstruction of the teaching paradigm. The focus of this study is on this smart teaching model empowered by digital twin technology. By establishing theoretical in-depth interaction between the three-dimensional virtual scenario and physical teaching space, it realizes the organic integration of the real situation knowledge application stage and the thinking training stage. Although the paradigm-related teaching reform, driven by technology, broadens the borders of cognition there are difficulties that involve the bottleneck of the real-time interaction of multi-source data as well as the limited technical adaptability of both teachers and students. In this regard, researching the cultivation mechanism of this teaching model for higher-order thinking is important, not only as a breakthrough in educational technology theories but also as a breakthrough to improving the quality of education for efficient learning.

Keywords

Digital twins
Higher order thinking
Smart teaching

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1. Introduction

The structural inadequacy of higher-order cognitive ability hinders the capacity to develop creative talents effectively. The conventional classroom concentration on knowledge indoctrination does not satisfy the higher-order cognitive growth goals of analysis, evaluation, and creation. With the functional application of digital twin technology, it breaks through the obstacles of two-dimensional digital resources. The capabilities of digital twin technology in simulating physical properties, reasoning over dynamic processes, and visualizing decision-making, as applied in teaching situations, gives the technical potential to develop an immersive cognitive space. This study is based on both constructivism and situational cognition theory in relation to learning by designing a pedagogic framework combining interaction with virtual and real, allowing learners to perform exploratory practice in the digital mirror world. This learning environment and the coexistence of virtual and real, turns cognitive load into an initiating force for the development of thinking. It also supports the shift in teaching from the experience transmission paradigm to ability construction paradigm.

2. Theoretical Basis of Cultivation of Higher-Order Thinking Skills and Digital Twin Wisdom Teaching

2.1. Principles and Characteristics of Digital Twin Technology

Physical objects are consistently gathering operational data from multi-source sensors and relaying features such as temperature and vibration, along with energy consumption, back to the virtual model in real time. The virtual dimension creates an operational mirror image that evolves in a three-dimensional way that is dynamic and behaves in tandem with the physical object, as it calibrated the state of the model based on the input data stream. This technology allows for the simulation to assume the dynamisim that can courtyard event in physical, whereas traditional/current simulation has always been static. Something like a comparative stress test from the virtual environment for example, could inform real world operation and maintenance decisions. The real value of this technology, however, is the ability to make a high-fidelity dynamic mapping across the entire life cycle, where operation and maintenance staff could use the virtual mapping to pre-judge the health status of their equipment and change the operating parameters of it safely prior to a failure of the physical object. These technical characteristics are especially expressed in the real time, two-way closed-loop feedback, the accuracy of convergence of multi-dimensional data, and the capacity for predictive capabilities across time and space cross-deduction. These characteristics transform abstract physical laws into visible and controllable digital logic chains. When transplanting this technology into the teaching scenario, it is necessary to reconstruct the data collection method, using learning behavior trajectories instead of industrial sensors as the core data source to ensure the dynamic presentation of the real cognitive process in the virtual teaching environment [1].

2.2. Relevant Theories of Digital Twin Wisdom Teaching

Situational cognition theory stresses the bonding of knowledge generation to certain situational learning situates that the realistic environment provided by digital twin technology to have a highly restored learning field where simulation learning requires reflective thought, voluntary and monitoring's change of body and mind respectively as students are required to demonstrate operational sequences or use process elements to conduct an experiment. The constructivist view of learning understands cognitive subjects to construct a knowledge system during a merging sequence of deconstructing and reconstructing information. The virtual mirror world allows students to manipulate or adjust parameters repeatedly to experience the change in the system. The embodied cognition theory understands the shaping influence of physical experience on the development of thinking development. The sensory feedback loops for motor representation come into play when students are manipulating descriptions and relationships of three- dimensional models like buildings, parts of buildings and cities, which must have supportive entities and elemental properties. Educational neuroscience validates an association—an enhanced neural plasticity for using diverse multimodal interaction approaches. A representational model learning configuration, with interactive virtual and real characteristics creates a teaching space that simultaneously activates the visual cortex and the motor cortex's neural pathways. The technology acceptance model describes to what extent teachers' and students' user willingness impacts teaching effectiveness, and that operational fluency of a system's interface relates directly to effective cognitive resource allocation. The cognitive load theory has been proposed as an optimization plan for working memory capacity. Finally, digital twin technology explicitly decomposes complex tasks to a visual operational steps that allow students to concentrate cognitive energy on the key links of their mental processes.

3. Construction of Digital Twin Intelligent Teaching Model for Cultivating Higher-Order Thinking Skills

3.1. Design Concept of Teaching Model

The digital twin intelligent teaching model broadens the teaching space that is capped by the constraints of physical space to a fluctuating virtual mirror world where the learner can authentically move through a complete problem- exploration cycle using concepts in immersive scenarios. The design is an iterative process and therefore the element of structural training of the abilitiy to explore core contradictions was occurring. The virtual environment allows the physical parameters that are difficult to attribute in a real environment to become quantifiable simulation variables; furthermore, students can observe the non-linear systems chain reaction through parameter- adjustment. The teaching model utilized in this study, distributing ease of cognitive load with the premise of scientific distribution in order to avoid failures of attention and resource allocation in learners. This technology supported platform does provide the support of cancellable-use high density cognitive activities including conducting concept modelling and scheme verification, allowing it to circumvent failure-of-attention or failure-of-resource allocation gaps in traditional experiments. Teachers become designers of cognitive flow lines instead of pre-scripting the deduction of systematic thinking for students. They establish conflict situations for learners to consciously and actively conduct systematic thinking deduction and building a "hypothesis-verification-iteration" learning loop in the twin environment. This designer representation can essentially be described as designing ways to create fields for thinking gaps, whereby digital means are used to allow for thinking gaps as a concrete operational carrier for the abstract thinking operations to collaboratively abstract, adapt, justify and construct measures to exhibit the development of the ability to solve real and complex problems [2].

3.2. Structural Framework of Teaching Model

This teachnig model is centered on real-time data exchanges between the physical teaching environment and a virtual mirror environment, creating a bi-derational cognitive channel that runs between the physical world and the digital space. The twin data layer continually captures the dynamic trajectories of learning behaviors and changes operational records into visual maps of the thinking process. The analysis platform at the teacher-end is identifies the salient transition nodes of high-order thinking from the behavior maps, and produces pragmatic intervention strategies for barriers to concept integration. The virtual operation console endows students with the technical capacity for the independent enactment of complex systems. Learners can observe the mutual contingency of cross-dimensional variables by superimposing parameter modules and confirm novel solutions under critical states in a risk-free environment. In the physical classroom, the materialization practice of cognitive accomplishments simultaneously takes place. The operational data in the physical context is immediately fed to the virtual model to initiate a new round of deduction and optimization, constructing a cognitive feedback loop of "mutual drive between virtual and real - dynamic iteration." The system is specially equipped with a cognitive scaffolding adjustment function. Teachers can release the operation permissions of system variables in stages according to the learners' thinking advancement needs to achieve an adaptive match of cognitive difficulty.

3.3. Implementation Process of Teaching Model

Educators proposed core driving tasks as real-world problem situations in the physical space, allowing learners to engage in self-governed conceptual model construction in the twin, or mediating, environment to map real-world systems. The virtual environment provides real-time control channels for designated pre-set parameters, allowing students to experiment with the evolution of variable relationships in the physical space while engaging in continuous iterative operations with multiple factors working together. The teaching system captures the cognitive decision-making sequence(s) in the operation trajectories. If the model output differs from the intended goal, it automatically pushes interdisciplinary background information to assist the scheme correction reference, promoting deeper learning through reflective thinking on the operating mechanism of the complex systems. In the physical space, collaborative argumentation sessions are staged. Group partners design their prototype physical devices based on the conclusions of the virtual experiments, and the abnormally generated data from the operational process feeds synchronously to the digital mirror to promote model auto-calibration. The learning process design dynamically sets the iterative intensity in accordance with cognitive load. As learners progress to higher levels of thinking, the learning process adds cognitive conflict task packages in the virtual space to simulate decision-making stress tests under extreme conditions.

4. Optimization Strategies of Digital Twin Wisdom Teaching Model for Cultivating Advanced Thinking Skills

4.1. Optimization Strategies of Technology Iteration and Adaptation

Technology developers explore and develop lightweight edge computing nodes intended to be instantiated at the physical equipment end in the laboratory, so the data volume of physical parameters transmitted to the cloud virtual entity would be compressed, thereby reducing a computing delay of high-frequency data transmission. The heterogeneous data fusion engine embeds cross-platform compatible protocols which will automatically convert the signal formats that are output by sensors of different brands to erase any model deduction errors that might happen in the process. The interface design team rearranges the functional partitions of the 3-dimensional operation panel in their design according to the cognitive load theory as a method to reassign multi-dimensional variable control instructions to progressive task chains and organize dynamical high-frequency operation functions into floating short cut menus. The education management department leads the off-peak scheduling mechanism of regional computing power resources, leveraging cooperative inter-school partnerships to form a distributed cloud computing pool, which allows for the automatic execution of the pre-loading tasks of twin models in the off-peak periods of nightly teaching hours. The multi-modal interaction interface develops a contactless gesture recognition layer, which allows teachers to wake up the relevant data monitoring panel with the course of gesture trajectories to select key modules of the virtual model, reducing the cognitive conversion cost of the concurrent operations of multi-task components [3].

4.2. Optimization Strategies of Teaching Methods and Activity Design

The instructional designers decompose the operation processes of complex systems based on the infrastructure level of customary schools and reduce multi -dimensional parameters regulation tasks to three-level progressive operation cards. The cards each only have variable adjustments tasks of a single cognitive dimension, lower the threshold to enter. The operation manual also provides low-cost conversion plans for physical teaching aids, which support the teachers and students in recycling everyday utensils such as electromagnetic relays and temperature sensors into a basic data collecting node and walking through mapping a simplified three-dimensional model the tablets were able to generate in real-time and instantaneously get verifiable about core principles, together. The activity script contains a cognitive anchor point generation mechanism. Each time individual students progress through a set of virtual-real contrast experiments, will trigger an automatic fill function of a mind map. The learning system will contrastingly work against the current operation pathway to the logical model of how we embedded the experience, using the interface and highlighted the deviation nodes within other areas. The teacher training workshop created a inter-school cooperative circle. The inter-disciplinary teaching groups collaborated together to make fault diagnosis case templates. When students' virtual models are simulating a logical conflict situations, a set of correction pre-plans will automatically be pushed from the relevant subject teachers to vegetate collective wisdom to be involved in the solutions process. Classroom management buttresses the touch-control guidance connection. As students then drag evidence of the virtual components into the designated space on the touch-screen, the system simultaneously projects a monitoring picture of the blind operation area onto the physical experiment table, bridging the perceptual discontinuity between abstract deduction and embodied practice.

4.3. Optimization Strategies of Teachers' and Students' Ability and Literacy Enhancement

When students' virtual models will be simulating and logically conflicting situations, a suite of correction pre-plans will be pushed from the appropriate subject teachers to vegetate collective wisdom to acknowledge and be involved with the 'solutions' process. Classroom management underpins the touch-control guidance association. As the students drag evidence of the virtual components into the appropriate area on the touch-screen, the dimensional controlling system equally plays a monitoring graphic of the blind operation area out onto the physical experiment table, thereby reconciling the perceptual discontinuity of abstract deduction and embodied practice. Student competence certifications can be incorporated in the physical teaching aids transformation task indicators group collaboration will be monitor discarded sensors were transformed into simple data acquisition nodes after filmed the transformation process narrative context and uploaded the transformed narrative context to the platform the twinning system onboarded adaptability for the modified physical characteristics of the digital detect and send back the physical evaluation report. the teaching assistant functionality incorporates an explicit cognitive load monitoring module for both the teacher and the student which automatically pushes the folding diagram of the operational path once students slip the operational interface without enacting an effective command multiple times, and synchs and reminds the teacher because they need to intervene in the guidance session of embodiment [4].

4.4. Optimization Strategies of Management Mechanism and Resource Allocation

Laboratory administrators combine old equipment to build a regional shared parts warehouse, dismantle and arrange usable sensors from meaningless instruments into twin system supplementary packages, and offer schools with limited budgets low-cost physical data collection terminals. The regional scheduling centre uses a changing resource allocation algorithm which dynamically de-couples practical project demand priorities when multi-school curriculum schedules indicate that synchronous invocation of high computer power modules is necessary, exporting the distribution of the remaining computing resources (of the distributed cloud) to rural schools. The equipment operation and maintenance warehouse has developed a prediction model concerning the deterioration of critical components and has prepared quarterly maintenance schedules based on past utilization packets; the warehouse forwards spare circuit boards to the high-usage schools two weeks in advance, to mitigate against equipment failure problems. The technical maintenance station also allows teachers access to open seasonally for independent maintenance guidance. Scanning the two codes on the faulty equipment can wake the three-dimensional disassembly demonstration animation. The maintenance technician would remotely label the location of the multimeter testing point assess to send guidance to the field personnel to check the line step-by-step. The spare parts turnover system connects the material databases of all schools in the county. Idle multi-channel capture cards automatically enter the cross-school flow sequence after a school completes a high-level push task, and the cloud-based inventory map displays in real time the models of adapters that can be rented by neighboring schools [5].

5. Conclusion

The smart teaching mode enabled by digital twin technology makes it possible to render abstract thought processes, allowing for the construction of an embodied cognitive field. In this virtual space, any change in the parameters triggers instantaneous feedback, thus prompting the learners to improve systematic thought through the interaction of multi-dimensional variables, and to enhance decision-making capacity through the trial-and-error iteration, which is exactly the core path for developing higher-order thinking. Therefore, relying on the collaborative breakthroughs of edge computing and artificial intelligence will help to address the mathematics and data integration challenges within the current application of technology; teacher and student digital literacies must rely upon a stratified training mechanism. The true value of this model is the reconfiguration of one form of education supply, when the limitations of experience in the physical world become infinitely embellished in the digital space, critical reflection, and exceptional reconstruction become the new norm of learning. Future research that explores the logic of constructing cross-disciplinary knowledge maps in a twin environment will allow us to allow technology empowerment to be transformed to the kinetic energy of thought evolution.

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