Digital intelligence empowers the ontology of mechanical professional education evaluation

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Abstract: The rapid development of digital intelligence technology is reshaping the underlying logic of vocational education evaluation. Mechanical professional education, in particular, faces a profound conflict between technical rationality and humanistic values. Starting from the crisis in educational evaluation triggered by the technological revolution, this paper reveals how algorithmic scoring systems dissolve educational subjectivity, how sensor data flows disenchant the embodied knowledge of craftsmen, and how digital twin technology challenges the practicality of teaching practices. Through ontological reconstruction, this paper proposes a shift from an "entity ontology" to a relational ontology evaluation system characterized by the synergistic evolution of "Human-Technology-Environment". This paper calls for building an awakened educational future, cultivating "Digital Craftsmen" who possess both intelligent control capabilities and humanistic care, thereby achieving the dialectical unity of technological empowerment and the preservation of humanity.

Keywords: Vocational Education; Digital Intelligence Empowerment; Educational Evaluation; Ontological Reconstruction

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1 The Impact of Digital Intelligence: Evaluation Crisis and Contradictions in Mechanical Professional Education

1.1 Technological Alienation: The Dissolution of Educational Subjectivity and Practical Reality

1.1.1 The Usurpation of Instrumental Rationality

With the advancement of educational technology, algorithmic scoring systems are widely used to evaluate CNC programming, yet they also pose risks of eroding educational subjectivity: the marginalization of the teacher's role, shifting from evaluator to algorithm supervisor, and students pursuing algorithmic approval, reducing educational relationships to data exchange. This not only deprives teachers and students of cognitive interaction but also inhibits students' creative thinking. Algorithms emphasize standardized answers and rigid thinking, leading students to adopt conservative strategies during training and abandon exploration of new solutions. From a philosophical perspective, this reflects the erosion of educational value by technological instrumental rationality. Heidegger argued that the revealing of modern technology has a challenging character, while the Frankfurt School pointed out that the expansion of instrumental rationality promotes the formation of social identity, neglecting the humanistic value and emancipatory function of education, leading to the homogenization of student thinking. Embodied theory in phenomenology indicates that algorithms cannot evaluate the "tacit feel" and situational knowledge in programming, such as when an algorithm negates a technician's ability to adjust parameters based on intuition. Therefore, while algorithmic scoring systems improve efficiency, vigilance is needed against their potential harm to educational subjectivity and creativity.

1.1.2 The Disenchantment of Embodied Knowledge

In traditional mechanical machining, the craftsman's tactile experience is the core of skill inheritance, formed through deep interaction between the body and the machine tool, such as tactile perception of tool vibration and auditory identification of cutting sounds. However, with the proliferation of sensor technology and data-driven evaluation systems, this embodied knowledge faces the risk of being replaced. Sensors quantify machine tool status into digital signals, replacing the craftsman's subjective judgment. While this enhances the objectivity and efficiency of evaluation, it marginalizes the operator's bodily perception, reducing interaction with the machine tool to data observation. Furthermore, data-driven systems overlook the value of contextualized knowledge, such as the craftsman's adaptive adjustments to specific environments. This reflects the suppression of embodied cognition by technical rationality, raising philosophical questions about the balance between "quantification" and "qualitative" aspects in skill evaluation. How to utilize sensor technology to improve efficiency while preserving and developing the craftsman's embodied knowledge becomes a key challenge in reconstructing the vocational education evaluation system.

1.1.3 The Dilemma of Virtual-Physical Integration

Digital twin technology, as a key technology of Industry 4.0, is reconstructing the spatiotemporal order of vocational education and challenging the practicality of teaching practices. Traditional teaching relies on physical space, where students operate on real machine tools to acquire skills. Digital twin technology creates virtual simulation environments, realizing a "physical-virtual" dual reality. Teaching activities extend to virtual platforms, and the time dimension becomes more flexible. While this offers new possibilities such as remote practical training and simulation of high-risk operations, it also raises many questions. Virtual operations differ fundamentally from physical operations, such as the lack of tactile feedback and the simulation of material property changes. The predictive nature of digital twins alters the temporality of teaching, potentially weakening students' ability to cope with uncertainty. The coexistence of virtual and physical spaces may also lead to cognitive dissociation, making it difficult for students to adapt to real-world environments. This challenges the foundational practicality of traditional teaching and prompts philosophical reflection on the essence of vocational education. How to ensure the authenticity and effectiveness of teaching practices in a world of virtual-physical integration? How to establish connections between virtual simulation and physical operation to avoid cognitive disconnection? These questions require an in-depth exploration of educational theory and practice.

1.2 Professional Contradiction: The Tension Between Technical Rationality and Experiential Tradition

1.2.1 The Binary Opposition in Precision Manufacturing

The field of precision manufacturing has long harbored a tension between technical rationality and the craftsman spirit, a tension that becomes more pronounced in the era of smart manufacturing. Technical rationality emphasizes scientization, standardization, and quantifiability, achieving manufacturing optimization through precise calculation, strict control, and real-time monitoring. However, the craftsman spirit is rooted in practical accumulation and bodily perception, emphasizing intuitive understanding of materials, mastery of equipment through "feel," and personalized adjustment of processes. In the context of the popularization of smart manufacturing technologies, technical rationality seeks to replace craftsmen's experiential judgment but is not always successful. In the machining of certain complex materials or the manufacturing of non-standard parts, the craftsman's experience can effectively compensate for the shortcomings of algorithmic predictions. This tension reflects the differences between the two knowledge systems and reveals the dialectical relationship between "science" and "art" in precision manufacturing. Therefore, preserving and developing the experiential tradition of the craftsman spirit within the framework of technical rationality has become an important task in the era of smart manufacturing. This requires technological innovation, such as developing intelligent algorithms that incorporate expert experience, while also re-examining the value balance between technical rationality and experiential tradition, cultivating "Digital Craftsmen" who are proficient in digital tools and deeply understand the essence of craftsmanship.

1.2.2 The Transformation of the Ternary Relationship in the Industrial Internet

The advent of the Industrial Internet era has given rise to a new paradigm of the "Human-Machine-Data" ternary relationship, which has profound implications for the intelligent transformation of manufacturing and vocational education. Traditional vocational education focuses on the "Human-Machine" binary relationship, emphasizing skills in operating and maintaining equipment. However, the proliferation of the Industrial Internet introduces "Data" as a new element, forming a new mode of human-machine collaboration. Operators need to interact with physical equipment while simultaneously monitoring equipment status, analyzing data, and optimizing processes. This places new demands on vocational education: students need to master equipment operation skills as well as data acquisition and analysis capabilities. However, current vocational education faces multiple dilemmas, including a disconnect between curriculum content and Industrial Internet technology, insufficient practical training conditions, and shortcomings in the competency structure of the teaching faculty.

These dilemmas reflect the time lag between technological change and educational adaptation, and also reveal systemic lags in vocational education regarding training objectives. Therefore, it is necessary to reposition the "Human-Machine-Data" ternary relationship, construct a new skill-training system adapted to the Industrial Internet era, and promote a paradigm shift in vocational education from equipment-oriented to data-intelligence-oriented.

2 The Ontological Turn: Evaluation Logic from Entity to Relation

2.1 Critiquing "Skill Atomism"

The traditional vocational education evaluation system tends towards "Skill Atomism," decomposing complex skills into isolated, static indicators and attempting to assess overall competence by quantifying each sub-item. However, this evaluation model overlooks the processual and relational nature of skill formation. As Whitehead's process philosophy reveals: "The reality is the process, and the process is the becoming of actual entities," which is the "generation of experience." For example, machining accuracy in CNC machine tool operation depends not only on parameter settings but also on the operator's dynamic adjustments in specific situations. Skill Atomism not only leads to assessment bias but also obscures practical wisdom—the tacit knowledge in real-world scenarios. Therefore, vocational education evaluation needs to shift from an "entity-oriented" atomistic assessment to a "process-relation-oriented" holistic evaluation, focusing on the dynamic interactions, temporal extensions, and ecological interrelationships in skill generation, thereby touching the essence of professional competence.

2.2 Constructing a "Human-Technology-Environment" Synergistic Network:

2.2.1 The Embodied Cognition Dimension

The essence of embodied cognition in machine tool operation lies in the dynamic coupling between the body and the equipment. The experience of traditional craftsmen, such as perceiving tool vibration through touch and adjusting feed force through muscle memory, constitutes a form of "bodily knowledge." However, the introduction of tactile sensors transforms this intuitive bodily perception into quantifiable data streams, such as vibration spectra and pressure waveforms, encoding the "tacit feel" into physical signals. While this datafication enhances evaluation objectivity, it may obscure the complexity of tacit knowledge—for instance, the craftsman's perception of subtle changes in material toughness is reduced to a numerical comparison, leading to the loss of contextualized judgment. The reconstruction of evaluation in the embodied cognition dimension requires preserving an interpretive space for bodily experience within datafication and developing multimodal models that integrate biological characteristics (such as EMG signals and skin resistance) with equipment data to capture the emergent wisdom in the interaction between the operator and the machine tool.

2.2.2 The Technological Intentionality Dimension

As a technological artifact, the design of CAD software interfaces carries implicit value loads, presetting specific technological intentionality through menu structures, default parameters, and operational procedures. For example, parametric design modules by default emphasize geometric accuracy and standardized production, potentially inhibiting innovative thinking for non-standard parts; the visualization logic of finite element analysis functions equates structural optimization with stress minimization, shaping students' engineering decision-making orientation. This implicit value orientation causes evaluation standards to unconsciously lean towards the technical rationality built into the software, neglecting diverse design possibilities. Critical evaluation needs to reveal the influence of algorithmic biases, such as comparing the solution recommendations of different CAD systems for the same design task, analyzing how tools discipline cognitive paths, and then reconstructing the dimension of technological democratization in the evaluation system, encouraging students to reflect on the ideological framework behind the tools.

2.2.3 The Environmental Generativity Dimension

The virtual-physical integration scenarios of smart factories reconstruct the ecological boundaries of teaching evaluation. Industrial Internet of Things and digital twin technologies embed evaluation standards into dynamic production systems, requiring attention to students' ability to synchronize the optimization of virtual and physical processing parameters and to coordinate multi-equipment production. The environmental generativity dimension pushes evaluation from individual operation towards system responsiveness, ecological interactivity, and cross-domain collaboration. This dimension highlights the synergistic evolutionary logic of "Human-Technology-Environment": the intelligent environment reconstructs evaluation standards, while students' innovative practices can, in turn, feed back into the iterative improvement of environmental rules. The evaluation system needs to shift from static competency checklists to the analysis of dynamic relational networks, constructing indicators that capture the value of "human-machine symbiosis," such as assessing the ability to use data feedback to optimize digital twin models, cognitive flexibility in switching between virtual and physical scenes, and critical awareness of the implicit values within technological systems.

3 Educational Response: Transformation Paths and Future Vision for Mechanical Professional Education

3.1 The Triple Consciousness of Digital Intelligence Evaluation

Under the new engineering paradigm, deeply integrated with Industry 4.0 and smart manufacturing, mechanical engineering education faces the need to leap from tool application to system-construction capability. Based on the cognitive, value, and practical dimensions of digital intelligence capability, starting from the three-dimensional digital literacy framework of "technological cognition – ethical reflection – engineering innovation," the path advances towards the progression of digital literacy for mechanical talents.

The reconstruction of technological cognition emphasizes the establishment of a data-driven knowledge architecture, encouraging students to transcend traditional mechanical engineering boundaries and deeply understand cutting-edge technologies such as the Industrial Internet of Things, machine learning, and digital twins. The value dimension emphasizes the ethical constraint framework for intelligent technologies, covering core issues such as data governance, algorithm transparency, and human-machine rights and responsibilities. Taking collaborative robots as an entry point, we advocate for techno-ethical design to ensure the harmonious coexistence of technological innovation and social values. The practical innovation dimension focuses on cultivating the closed-loop engineering thinking of "digital modeling – simulation verification – physical iteration." Through project practices such as smart production line optimization and equipment whole-life-cycle digital twins, students will master cross-domain system integration capabilities, enabling multi-constraint simulation verification of structure-function-manufacturing and ensuring the precise mapping of digital models to physical entities.

3.2 The New Mission of Mechanical Professional Education

The era of smart manufacturing has redefined the competency map for mechanical talents, prompting a triple shift in educational objectives:

The cultivation of algorithmic criticality needs to go beyond tool use. In MASTERCAM courses, students are required to reverse-engineer the decision-making logic of CAM software by comparing the algorithm-recommended solutions for the same part with the results of manual programming by engineers, revealing the efficiency-first tendency behind parameter optimization. This training enables students to both use algorithms skillfully and critique their value loads, becoming "conscious users" of technological systems.

Digital embodied wisdom emphasizes the bodily presence in the integration of the virtual and the physical. In robot-welding instruction, students need to alternate between force-feedback gloves and physical welding torches. Teachers assess the completeness of their "technological embodiment" through bimodal data of EMG signals and weld formation. This wisdom rejects the "virtual substitution theory," insisting on bodily perception as the foundation of cognitive generation.

The shaping of technological ethical awareness concerns the sustainable development of industrial civilization. A certain school-enterprise cooperation project sets up "ethical conflict scenarios" that require students to handle the paradoxical demands of improving OEE and extending tool life. Through teaching methods such as role-playing debates and constructing ethical decision trees, students cultivate the wisdom to balance multiple values, including efficiency, safety, and environmental protection.

4 Conclusion: Towards an Awakened Educational Future

The rapid advance of digital intelligence technology pushes mechanical professional education into the ultimate game between efficiency and humanism. It demands breaking the myth of "algorithm worship" and reconstructing the existential connotation of digital literacy – technological disenchantment: Digital literacy is no longer just a tool skill, but survival wisdom integrating the virtual and physical, such as encoding the craftsman's feel into a vibration spectrum library, realizing the digital rebirth of embodied experience.

Educational Return: The evaluation system needs to shift from "machine adaptation" to "life growth," adding a manual intervention interface to CNC programming assessments and incorporating technological inclusivity indicators into intelligent equipment development, making education the guardian of humanistic values.

Civilizational Mission: Mechanical professional education should transcend the "art of making instruments" and become a reflective ground for technical rationality. The future "Awakened Craftsman" is both the master of intelligent systems and the ferryman of the civilizational spark. This requires vocational education to construct a cultivation paradigm of "digital survivability," anchoring the essence of education amidst the flood of algorithms and data, writing an educational epic that transcends technological determinism for human civilization.

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