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Design and Teaching Practice of Ideological and Political Elements in the Course of Mechanical Engineering Materials

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Abstract: This study takes the course “Fundamentals of Mechanical Engineering Materials” as a platform to explore ideological and political elements within the "material properties-process technology-engineering applications" knowledge chain. By employing case studies, project-based learning, and other diversified pedagogical approaches, the organic integration of professional knowledge and value-based education is achieved. A three-dimensional "History-Technology-Ethics" integration model is constructed, and a hierarchical curriculum system of ideological-political case studies is developed. Five representative teaching cases are introduced to validate the effectiveness of this approach in cultivating students’ engineering ethics, social responsibility, and patriotic sentiment.

1. Introduction

With the implementation of the “Guidelines for Ideological and Political Construction in Higher Education Courses” [1], there is an urgent need to establish teaching paradigms that unify professional knowledge with value cultivation in engineering education. As a core course in equipment manufacturing, “Mechanical Engineering Materials” inherently encompasses ideological elements such as technological innovation and engineering ethics. However, current teaching practices often suffer from superficial "labelling" or forced "implantation" of ideological content, characterized by disconnections between ideological elements and knowledge systems, as well as monotonous teaching methods [2].

Addressing these challenges, this study proposes a three-dimensional "History-Technology-Ethics" integration model and develops a hierarchical case library. Over three years of iterative teaching practices, we observed that the pedagogical path of "technical parameter analysis → engineering value decoding → societal impact deduction" enhances students’ engineering decision-making capabilities and social responsibility [3].

2. Manuscript Preparation (Heading 2)

Based on constructivist learning theory and engineering education accreditation standards, this research constructs a three-dimensional "History-Technology-Ethics" integration model (Figure 1). This model vertically traces the evolution of material civilization, horizontally links critical technological breakthroughs, and deeply embeds engineering ethical judgments, forming a multidimensional ideological education system.

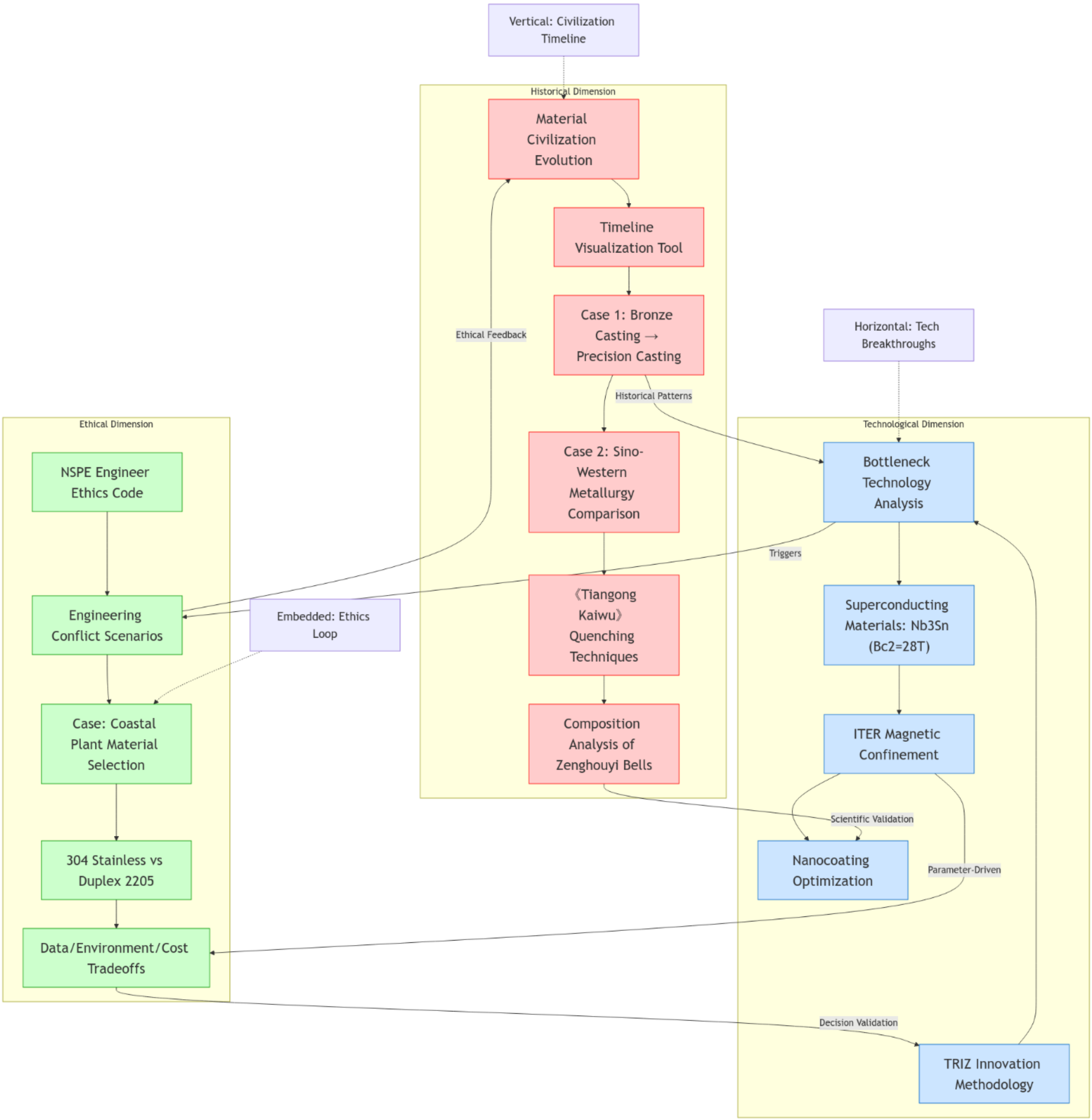

Figure 1: Three-dimensional "History-Technology-Ethics" Integration Model.

2.1. Historical Dimension

A cultural identity pathway is established through the history of material development to strengthen cultural confidence. For instance, the technological evolution from ancient bronze "mold-casting" to modern precision casting reveals the inheritance of Chinese craftsmanship. When teaching heat treatment, historical records such as the "Five Quenching Methods" from “Tiangong Kaiwu” are integrated with compositional analyses of Zenghouyi bronze chimes, guiding students to understand the scientific principles behind traditional techniques. Visual timelines comparing Western steel production surges during the Industrial Revolution with China’s stagnant metallurgical technology further inspire reflections on "technological self-reliance."

2.2. Technological and Ethical Dimensions

A closed-loop training mechanism of "technological breakthrough → value conflict → ethical decision-making" is established.

Technological Perspective: Innovation is cultivated through breakthroughs in "bottleneck technologies," such as analysing the quantitative relationship between Nb3Sn superconducting wire’s critical magnetic field and ITER fusion reactor requirements using TRIZ methodology.

Ethical Perspective: Engineering conflict scenarios are designed to reinforce responsibility. For example, in corrosion protection lessons, students weigh material choices (e.g., cost-effective 304 stainless steel vs. durable duplex steel 2205) for coastal chemical plants while adhering to NSPE’s ethical principle of "issuing statements based solely on objective truth".

3. Case Design and Implementation

3.1. Case 1-High-Speed Railway Wheel Steel Development—Material Strength and National Technological Independence

3.1.1. In-depth Analysis of Knowledge Points and Technical Practice

In-depth analysis of knowledge points and technical practice is supposed to be implemented as follows.

Micro-alloyed grain boundary regulation mechanism: With CL70 wheel steel as the object, the grain boundary pinning effect produced by the precipitation of carbonitrides of vanadium element is analysed. And combined with EBSD grain orientation analysis, its action path to increase the yield strength to ≥650MPa is clarified.

Ultra-pure smelting process control: Oxygen content control experiments are conducted for double-vacuum smelting (VIM+VAR). Through GDMS detection, it is verified that the optimization of process parameters can stably control the oxygen content to ≤15ppm and reach the cleanliness standard of aviation bearing steel.

3.1.2. Multi-stage Ideological Integration Strategies

Multi-stage Ideological Integration Strategies are designed as follows.

Pre-class cognitive construction: A case library of the 2016 high-speed train wheel axle fracture accident of German BVV Company is designed. Students are guided to compare the service data of Chinese and German wheel steels (including hardness gradient distribution, non-metallic inclusion rating, etc.). A technical gap analysis report is written.

In-class exploration and verification: A phase transformation kinetic model of 25CrMo alloy steel is established using JMatPro software. The students are guided to quantitatively analyze the influence law of molybdenum element content (0.15 - 0.25wt%) on the fatigue crack growth rate (da/dN). At the same time, the failure criterion of TSI standard EN13260 is correlated. Meanwhile, the video of the interview record of engineers from “Maanshan Iron and Steel Group” is embedded, and the key segment of "still insisting on domestic R&D after 200 failures in wheel steel composition debugging" is focused on intercepting. In cooperation with the metallographic structure evolution map, the spiritual connotation of "innovation and serving the country" is concretely shown.

Post-class innovation internalization: The "China's Bottleneck Materials Technology List" collaborative workshop is organized, and the TRIZ contradiction matrix method is used to propose innovative proposals for the strength - toughness coordinated optimization of high - speed train axle steel.

3.1.3. Assessment Methodology

A whole-process ability evaluation system is established.

Technical report (60%): The ability to analyze material characterization data is assessed as the primary focus, with specific emphasis placed on the quantitative analysis of SEM fracture morphology.

Innovation proposal (30%): Scores are assigned according to three-tiered evaluation indicators: innovativeness (40%), feasibility (30%), and engineering ethics compliance (30%).

Group peer-evaluation (10%): The CIPP model is systematically applied, through which peer-evaluation is conducted across defined dimensions including Context (goal fitness) and Input (resource utilization).

3.2. Case 2-Aerospace Bearing Heat Treatment—Modern Interpretation of Craftsmanship

3.2.1. In-depth Analysis of Knowledge Points and Technical Practice

In-depth analysis of knowledge points and technical practice is supposed to be implemented as follows.

Precise Control of Phase Transformation Kinetics: Based on the Time-Temperature-Transformation (TTT) curve for bainitic isothermal quenching, a temperature-time window model is established to quantify the relationship between retained austenite content and impact toughness.

Quantitative Characterization of Residual Stress: X-ray diffraction combined with a strain gradient compensation algorithm enables three-dimensional reconstruction of the gradient stress field in carburized layers.

3.2.2. Craftsmanship Cultivation

Three kinds of craftsmanship are supposed to be cultivated.

Teaching of "micro-meter spirit" in a contextualized manner: The production site video of Harbin Bearing Group is introduced and the causal relationship between size tolerance control and contact fatigue life in ultra-precision grinding is analysed.

Virtual experiment of process robustness: Through Deform-3D simulation, the impact of carbon content fluctuation on the martensite transformation temperature is simulated. The sorting of process parameter sensitivity is established: quenching rate > carbon potential > uniform temperature time.

Comparison and research of standard systems: Microscopic structure rating comparison matrix between NASA HBK-005 and GB/T 34891 is constructed to strengthen the awareness of the right to speak in standard formulation.

3.2.3. Ability-oriented Evaluation System

The ability-oriented evaluation system is established.

Process optimization plan (50%): Students are required to design a orthogonal test based on the Taguchi method to optimize the process combination of carburized layer depth and surface hardness.

Quality control flow chart (30%): A heat treatment process control plan, including 16 critical control points (CCP), is compiled using the APQP framework.

Operation specification video (20%): The quenching medium stirring operation process is recorded in accordance with the ISO 14731 standard, with emphasis placed on the evaluation of safety specifications and the degree of action standardization.

3.3. Case 3-Degradable Magnesium Alloy Bone Screws - Material Selection and Sustainable Development

3.3.1. In-depth Analysis of Knowledge Points and Technical Practice

In-depth analysis of knowledge points and technical practice is supposed to be implemented as follows.

Construction of in-vitro degradation model: A degradation rate equation of Mg-Zn-Ca alloy in simulated body fluid is established through electrochemical impedance spectroscopy (EIS) to predict the mass loss rate within 12 weeks.

Topological optimization of porous structure: Gibson - Ashby model is used to calculate the Young's modulus of porous magnesium alloy and thus achieve mechanical matching with bone tissue.

3.3.2. Value Guidance for Sustainable Development

Whole-life-cycle carbon footprint analysis: SimaPro software is used to compare the carbon emission intensity of titanium alloy (TC4) and magnesium alloy processing processes, and to correlate with the requirements of green manufacturing indicators.

Medical-engineering ethics debate design: Controversial issues such as "whether to accept a 5% deviation in elastic modulus" are set up, and multi-role debates are carried out in combination with ASTM F2504 pre-clinical test specifications.

3.3.3. Multi-dimensional Ability Evaluation Matrix

Analysis report (40%): An analysis report is prepared in compliance with the ISO 14040 standard, with the rationality of system boundary definition being systematically assessed.

Debate performance (30%): The improved CEDA scoring table is utilized, through which scores are assigned across three dimensions: argument scientificity (40%), ethical consideration (30%), and collaboration ability (30%).

Clinical demand research (30%): Three core demands of orthopedic doctors are extracted through on-site interviews conducted in hospitals, and a "Clinical-Engineering Demand Conversion Matrix" is subsequently formulated.

3.4. Case 4-Bolt Failure in Wenzhou Bullet Train Accident - Material Failure and Social Responsibility

3.4.1. In-depth Analysis of Knowledge Points and Technical Practice

In-depth analysis of knowledge points and technical practice is supposed to be implemented as follows.

Stress corrosion threshold calculation: Based on the slow strain rate test (SSRT), stress corrosion threshold calculation of Q235 bolts in seawater environment was carried out.

Fracture morphology diagnosis: The intergranular fracture characteristics are identified through SEM.

3.4.2. Cultivation of Social Responsibility Awareness

Accident investigation scenario restoration: A "bolt material selection decision tree" is constructed, and the differences in chloride - ion stress corrosion sensitivity between S31603 stainless steel and Q235 carbon steel are compared.

Engineering ethics sand table simulation: The Triple Constraints decision - making model (cost < 50 yuan/piece vs service life > 15 years vs failure rate < 1×10^-6) is developed, and students are required to apply Article Ⅲ of the NSPE ethics code when there are constraint conflicts.

3.4.3. Reflective Evaluation System

Failure analysis report (50%): Failure analysis report which focuses on assessing the logical rigor of the Fishbone diagram.is written according to the format of ASM Handbook Vol.11.

Ethics checklist (30%): "Material Selection Ethics Evaluation Table" with 12 indicators (such as the completeness of the environmental hazard early - warning mechanism) is designed.

Reflection log (20%): Kolb experiential learning cycle model is used to record the whole process of "technical judgment - ethical conflict - plan adjustment".

3.5. Case 4-Bolt Failure in Wenzhou Bullet Train Accident - Material Failure and Social Responsibility

3.5.1. In-depth Analysis of Knowledge Points and Technical Practice

In-depth analysis of knowledge points and technical practice is supposed to be implemented as follows.

Molten pool dynamics control: A regression model between laser power and molten pool depth is established, and the inter - layer overlap rate is optimized.

Crystal growth regulation: The ratio of columnar crystal/equiaxed crystal is controlled through Epitaxial Growth Index (EGI = G/R), and a fully columnar crystal structure is obtained.

3.5.2. Innovation Methodology Practice

Patent map analysis: The gradient support structure design strategy in the core patent (ZL201810005988.3) of Xi'an Bright Laser Technologies Co., Ltd. is decoded.

Micro-structure innovation challenge: Under the constraint of strength ⩾ 900MPa, a topological optimization plan is achieved by using nTopology software to reduce the blade weight by 18 - 22%.

3.5.3. Innovation Efficiency Evaluation

Topological scheme (40%): The scheme is scored according to the completion degree of the objective function (60%) and manufacturing feasibility (40%).

Patent analysis (30%): Derwent Innovation platform is used to complete the F - Term classification search and identify technical gaps.

Feasibility demonstration (30%): A report from three dimensions of technology maturity level (TRL), cost - benefit ratio, and environmental compatibility is required.

4. Conclusions

A three-dimensional integration model of "history-technology-ethics" is constructed, and the organic integration of engineering education and ideological and political education through the logical chain of "historical tracing-technological deconstruction-ethical reconstruction" is realized. In the future, this model can be further explored:

Dynamic adjustment mechanism: Teaching cases are updated in real - time according to the latest technological advances (such as room - temperature superconductivity breakthroughs);

International comparison dimension: The "craftsman spirit" in Japan and the ethical framework of Germany's Industry 4.0, etc., are introduced to enhance the cultivation of global competence.

This framework provides a replicable paradigm for the ideological and political construction of engineering courses and has the potential to be promoted to fields such as machinery and energy.

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