

Research Article

Interdisciplinary Integration in Design Education for the AI Era: A Case Study of Ceramic Product Design

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Abstract

In the context of artificial intelligence (AI) reshaping the design field, this paper explores how design education can address the innovative demands of the intelligent era through interdisciplinary integration. Taking ceramic products as a representative case, this study focuses on the convergence of cutting-edge technologies such as materials science, computer-aided design, and machine learning to construct a new design education framework tailored to the AI era. Employing theoretical construction and case analysis, this research elucidates the "Intelligent Ceramic Design" framework, integrating generative design, data-driven modeling, and additive manufacturing technologies to systematically explore innovative pathways for ceramic products in functionality, aesthetic expression, and sustainability. Concurrently, it examines the feasibility and challenges of technological integration. The findings indicate that interdisciplinary integration significantly expands the innovative dimensions of ceramic design at technological, educational, and industrial levels. Design education in the AI era must transcend traditional disciplinary boundaries, systematically merging intelligent technologies with traditional craftsmanship to cultivate versatile design talents equipped with design thinking, engineering literacy, and humanistic sensitivity. The case study of ceramic products demonstrates that interdisciplinary integration is a core strategy for design education to adapt to future industrial transformations. Future research should further explore mechanisms for balancing intelligent technologies with cultural heritage, as well as the potential applications of emerging technologies in design.

Keywords

AI Era, Design Education, Interdisciplinary Integration, Ceramic Products, Intelligent Design

1. Introduction

The advancement of artificial intelligence (AI) is profoundly reshaping global industrial ecosystems, and the design discipline faces unprecedented opportunities for transformation. Traditional design education, long confined to a unidimensional focus on skill acquisition and aesthetic cultivation, reveals limitations in the knowledge production paradigm of the intelligent era. Design education urgently requires

a framework for interdisciplinary knowledge integration to address the complex demands of intelligent, personalized, and sustainable development. This study selects ceramic products—a traditional craft medium embodying both functional utility and cultural symbolism—as its research subject, as their design innovation involves the intersection of multiple knowledge domains, including materials engineering, digital

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manufacturing, human-computer interaction systems, and cultural semiotics. Through a case study of ceramic design, this paper explores the transformative pathways and methodological systems for interdisciplinary integration in AI-era design education. [1]

2. Trends in Design Education Transformation

In the context of the intelligent era, ceramic design education is undergoing a profound shift from a single-discipline approach to interdisciplinary integration. The traditional linear curriculum centered on craft techniques is gradually being replaced by emerging interdisciplinary courses, such as parametric ceramic design and smart material applications, which combine computational thinking, materials science, and design innovation to drive breakthroughs in ceramic form and functionality. Meanwhile, data-driven user analysis has supplanted experience-based design decision-making, leveraging AI technologies to interpret user behavior and market trends, thereby enabling more precise and personalized product design. Furthermore, the adoption of digital fabrication and intelligent production technologies—such as 3D printing and robotic-assisted forming—has optimized manufacturing processes, reduced resource consumption, and made small-batch customized production feasible. Together, these transformations are advancing ceramic design from traditional craftsmanship toward intelligent and sustainable practices, opening new pathways for the future of the industry.

2.1. From Disciplinary Silos to Interdisciplinary Integration

Traditional design education systems often exhibited disciplinary barriers, with curricula typically organized along linear craft production processes - modular courses in ceramic form design, decoration techniques, and firing processes. [2] While this single-discipline approach ensured systematic transmission of craft techniques, it reveals growing limitations in the intelligent era.

Jingdezhen Ceramic University's pedagogical reforms exemplify the transition. While maintaining core traditional courses (e.g., wheel-throwing, glazing), the institution introduced a groundbreaking "Parametric Ceramic Design" interdisciplinary module. This course integrates parametric design platforms, material performance simulation systems, and programming languages, requiring students to generate structurally topology-optimized ceramic forms through algorithms and validate their mechanical properties. This approach not only transcends the empirical limitations of traditional form-making but cultivates computational thinking for complex design challenges.

The MIT Media Lab's "Programmable Matter" project further validates interdisciplinary necessity. By combining

shape-memory alloys with ceramic matrix composites, researchers developed temperature-responsive intelligent vessels. This breakthrough required materials scientists for composite formulations, computer experts for morphological algorithms, and designers to harmonize functionality with aesthetics - a powerful demonstration of multidisciplinary synergy. [3, 4]

2.2. Data-Driven User Analysis

AI is shifting design from experience-based to data-driven paradigms. Machine learning analysis of user behavior, market trends, and material properties enables optimization of ceramic products' functional and aesthetic qualities.

Contemporary AI processes multidimensional user data (consumption patterns, usage scenario videos, social media sentiment analysis) through machine learning algorithms, overcoming the limitations of traditional designer intuition and limited market research. This big-data approach enhances design objectivity and enables a philosophical shift from product-centric to user-need-oriented design. [5]

A Japanese ceramics company's smart tableware project illustrates this transformation. Using computer vision to analyze dining postures and temperature preferences revealed Asian consumers' preference for bowl thicknesses between 4.2-5.1mm - findings that directly informed parametric modeling of new bone china tableware. Subsequent application of generative adversarial networks produced regionally-appropriate decorative patterns, significantly improving market acceptance. [6]

2.3. Digital Manufacturing and Intelligent Production

Additive manufacturing and robotic-assisted forming are revolutionizing ceramic production. When combined with AI's real-time optimization capabilities, these technologies enable small-batch customization while reducing resource waste. [7, 8]

This represents a paradigm shift from "manufacturing-constrained design" to "design-driven manufacturing." The integration with AI optimization algorithms not only overcomes traditional production limitations but demonstrates significant sustainability advantages.

A Dutch-Belgian collaborative project exemplifies this potential. Their intelligent 3D printing system produces complex hollow structures in single operations, reducing material waste by over 50% compared to traditional slip-casting. [9] The system generates ergonomic tableware forms from user-uploaded parameters, achieving true mass customization.

On the industrial front, Japan's Komatsu Seiki developed a robotic pottery system that replicates master throwers' movements while incorporating real-time finite element analysis to adjust wall thickness distribution. Operational data

shows higher yield rates than manual throwing, with each piece allowing parametric adjustments - perfectly balancing craft quality with customization. This "digital artisan" model presents new technological pathways for traditional craft modernization.

3. Interdisciplinary Integration in Product Design

At the intersection of materials science, human-computer interaction, and sustainable design, intelligent technologies are profoundly reshaping the R&D paradigm of ceramic design. The integration of computational materials science and AI simulation has transformed ceramic formulation optimization and process control from experience-driven to data-driven approaches, significantly enhancing material performance and production efficiency. Meanwhile, the incorporation of human-computer interaction technologies expands the functional boundaries of ceramic products. Through smart sensing and digital translation, these innovations preserve the aesthetic essence of traditional craftsmanship while creating entirely new user experiences.

Furthermore, AI-enabled sustainable design methodologies, leveraging lifecycle assessment and low-carbon material optimization, are driving the ceramic industry toward environmentally friendly practices. These technological advancements not only address efficiency and resource challenges in traditional production but also open new possibilities in cultural preservation and ecological responsibility. Collectively, they mark the transition of ceramic design into an intelligent and sustainable new era. [10]

3.1. Materials Science and Computational Design

The performance of ceramic materials directly impacts product design. Through computational materials science, AI can simulate various formulations and firing processes to optimize ceramic properties. For instance, MIT's research team employed deep learning to predict deformation rates during ceramic sintering, significantly reducing defect rates and demonstrating the potential of computation-driven material innovation.

The convergence of materials science and computer-aided design is revolutionizing ceramic product development. While traditional material development relied on empirical trial-and-error, modern computational materials science enables precise performance prediction and optimization through multi-scale modeling and machine learning algorithms. This paradigm shift is particularly impactful in ceramics, where complex sintering kinetics and microstructural evolution present unique computational challenges. [12]

3.2. Human-Computer Interaction and User Experience

The application of HCI technologies in intelligent ceramic products is redefining user experience paradigms for traditional artifacts. These IoT-enabled, sensor-integrated products require not only solutions to complex technical integration issues but also the development of emotionally resonant interaction models grounded in cognitive psychology. Designers serve as crucial system integrators, tasked with striking a precise balance between engineering feasibility and optimal user experience.

From a cultural preservation perspective, the China Academy of Art's "Digital Blue-and-White" project exemplifies an alternative innovation pathway. By capturing users' gestural characteristics through pressure sensors and generating virtual patterns that adhere to traditional brushstroke rhythms via AR technology, this initiative successfully preserves the aesthetic essence of heritage ceramics while creating novel cultural experiences through intelligent interaction. This digital translation of intangible cultural heritage provides an exemplary model for contemporary representation of traditional craftsmanship.

3.3. AI and Sustainable Design

The application of AI in ceramic product lifecycle assessment is driving transformative changes in sustainable design. AI enables comprehensive visualization of environmental impacts across the entire value chain - from raw material extraction to end-of-life processing - providing quantitative foundations for design decisions. This data-driven approach to sustainability optimization is overcoming the limitations of experience-based judgment in traditional design practices. [11]

The "Low-Carbon Ceramics" research project jointly conducted by the Royal College of Art and Imperial College London developed a deep learning-based material selection system incorporating a global database of carbon footprints for over 300 ceramic raw materials. By analyzing multiple environmental parameters including local energy infrastructure and transportation distances, the system recommends optimal sustainable material combinations. Practical applications demonstrate significant reductions in per-product carbon emissions for British bone china production, achieved through optimized kiln control algorithms that minimize energy waste. The project team's "digital twin" recycling system further enhances sustainability by employing image recognition to automatically sort ceramic waste for material recovery, successfully demonstrating the compatibility of environmental responsibility and commercial viability. [13]

4. Case Study: "Intelligent Ceramic" Design Education

Contemporary ceramic education is undergoing a profound transformation from traditional craft instruction to intelligent, interdisciplinary training models. The emerging "Intelligent Ceramic Design" educational framework integrates generative design pedagogy, digital twin technology, and 3D printing processes to establish a teaching system that deeply combines theory with practice. In cultural heritage preservation, digital technologies not only enable intelligent analysis and innovative reinterpretation of traditional patterns but have also pioneered a dual-track "techno-archaeology + intelligent creation" preservation model.

Concurrently, through establishing industry-academia collaboration platforms, constructing interdisciplinary laboratories, and expanding international exchange channels, ceramic education is developing an integrated innovation ecosystem combining production, education, research, and application. These practices not only cultivate students' systemic thinking and innovative capabilities but also chart new developmental pathways for the contemporary transformation of ceramic art, marking ceramic education's entry into a new phase characterized by intelligent and internationalized development.

4.1. Practical Application Examples

The "Intelligent Ceramic Design" educational framework transcends the traditional craft pedagogy of singular skill transmission, emphasizing instead the cultivation of systemic thinking and innovative capabilities through real-world project scenarios. Generative design instruction adopts a "dual-track" approach: training students in commercial software while requiring the development of custom algorithms. Students who develop proprietary algorithms demonstrate greater creativity in solving non-standard problems. Digital twin pedagogy focuses on virtual-physical interaction, exemplified by the China Academy of Art's "Digital Mirror of Ceramic Factory," which enables real-time production parameter optimization.

3D-printed ceramics education has evolved into a complete process chain. The Royal College of Art's "From Algorithm to Kiln" workshop requires students to execute the full workflow from parametric modeling to post-processing.

Their 2023 exhibition piece, "Topology-Optimized Tea-ware," reduced material usage by 55% while preserving traditional white porcelain textures. Smart glaze development courses highlight interdisciplinary collaboration, as seen in the joint program between Tama Art University and Tokyo Institute of Technology, where materials scientists guide crystal growth simulations while designers oversee color manifestation. Their collaboratively developed thermo-chromic glaze has secured international patents.

4.2. Cultural Heritage Development

In cultural preservation, Jingdezhen Ceramic University's "Digital Intangible Heritage" project employs 3D scanning to reconstruct ancient ceramic fragments, then utilizes GAN networks to generate contemporary aesthetic patterns. This "tech-archaeology + intelligent creation" dual model establishes a digital repository of historical imperial kiln artifacts and trains specialized GANs to analyze ornamental evolution. The system's outputs retain the ink-wash subtleties of Ming Dynasty blue-and-white "gradient wash" techniques while incorporating parametric design language, earning the "Best Traditional Innovation Award" at 2023 Milan Design Week. This "technology-as-tool, culture-as-essence" methodology provides a replicable framework for living heritage transmission. [14]

4.3. Interdisciplinary Practice Education

4.3.1. Industry-Academia Collaborative Platforms

Joint initiatives with ceramic enterprises on "AI-Driven Intelligent Ceramic Product R&D" allow students to engage with industrial workflows, market demands, and technical specifications under dual mentorship. This ensures tight coupling between education and industry needs.

4.3.2. On-Campus Interdisciplinary Laboratories

Dedicated facilities like the "AI & Ceramic Innovation Lab" integrate equipment from ceramics, materials science, and computer science disciplines. Equipped with 3D printers, intelligent kilns, HPC systems, and experimental materials, these spaces enable projects in AI-aided design, novel material development, and digital process simulation, fostering research and innovation competencies.

4.3.3. Global Exchange Networks

International partnerships with academic institutions facilitate student exchanges, joint research (e.g., "AI-Based Global Ceramic Heritage Digitization"), and conference participation. These initiatives expose learners to cutting-edge technologies and pedagogies while enhancing cross-cultural competencies.

5. Challenges and Future Perspectives

The deep integration of intelligent technologies with ceramics education presents two fundamental challenges: technological convergence and cultural ethics.

At the technological level, interdisciplinary collaboration faces practical barriers including paradigm disparities between disciplines, incompatible standards, and the pressure of rapid technological iteration. The inherent divide between design aesthetics and engineering quantification requires urgent reconciliation.

On the cultural-ethical front, algorithmic homogenization

and technology-first thinking risk eroding the humanistic values embedded in traditional craftsmanship. The central dilemma lies in balancing technological innovation with cultural preservation. Current educational practices are exploring a "technology-as-tool, culture-as-core" integration approach, exemplified by initiatives like the "Digital Artisan" training model that embeds cultural gene within technological applications.

These explorations extend beyond pedagogical effectiveness, profoundly influencing how traditional crafts will evolve and endure in the intelligent era. They demand systematic consideration from educators at both methodological and philosophical levels, calling for a holistic reevaluation of how we preserve heritage while embracing innovation.

5.1. Technological Integration Complexities

The epistemic divide between design's intuitive thinking and engineering's quantitative rigor creates valuation mismatches—e.g., ceramic artists' focus on glaze aesthetics versus materials scientists' crystalline structure analyses—impeding early-stage collaboration. Technical incompatibilities between industrial design software and engineering simulation platforms further hinder system integration, as basic file conversions fail to preserve data integrity. Additionally, the rapid obsolescence of technologies (e.g., the shift from FDM to SLA in ceramic 3D printing) necessitates continuous curriculum updates across materials science, mechanics, and optics, challenging conventional teaching structures.

5.2. Ethical and Cultural Equilibrium

At its core, design remains human-centric; AI-mediated outcomes must ultimately serve humanistic values. [15] Current AI-generated designs exhibit three shortcomings: (1) algorithmic homogenization dilutes regional aesthetics, overlooking locality-encoded craft wisdom; (2) data-driven logic diminishes artisanal beauty, as seen when printing efficiency overrides handcrafted "imperfect perfection"; (3) techno-centric approaches risk cultural discontinuity, evidenced by Japanese tea masters' critique of purely algorithmic teaware as "lacking temporal resonance."

Pioneering programs like CAFA's "Digital Craftsman" curriculum address this by mandating traditional glaze application mastery before algorithmic design training. This "heritage-first innovation" model delineates technological boundaries while enabling cultural DNA translation through digital means.

6. Conclusions

The Transformation of Design Education in the Age of AI Requires Multidimensional Dialectical Thinking

Amid the dual backdrop of contemporary technological

revolution and cultural heritage preservation, design education is undergoing an unprecedented reconstruction. Ceramic products, as one of humanity's oldest forms of creation, profoundly reveal the dialectical relationship between technology and culture.

From a technological perspective, the integration of artificial intelligence and materials science presents a "double-edged sword" effect. Machine learning can significantly shorten the development cycle of new materials, yet algorithm-generated forms exhibit lower cultural recognizability compared to traditional design. This necessitates maintaining the human warmth of craftsmanship while adopting advanced technologies. Educators must develop more comprehensive evaluation systems that consider technical feasibility, cultural continuity, and environmental sustainability.

As the Chair of the Ceramics Department at Alfred University remarked, "The finest education in smart ceramics does not replace humans with machines, but cultivates a new generation of Renaissance designers who can master technology." In this new technological era, the ultimate goal of design education should be to nurture versatile innovators equipped with technical proficiency, cultural literacy, and ethical insight.

Abbreviations

AI	Artificial Intelligence
AI-Era	Artificial Intelligence Era
3D	Three Dimensional
MIT	Massachusetts Institute of Technology
AR	Augmented Reality
HCI	Human-Computer Interaction

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Author Contributions

Di Jinben: Conceptualization, Resources, Data curation, Investigation, Methodology, Writing – review & editing

Zhang Xiaojing: Data curation, Methodology, Supervision

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Conflicts of Interest

The authors declare no conflicts of interest.

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