

An Innovative Research on Practical Teaching Methods for Sustainable Design Courses in the Context of Interdisciplinary Integration

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Abstract: Against the backdrop of global sustainable development and China's "Dual Carbon" strategy, there is a growing societal demand for interdisciplinary, versatile sustainable design professionals possessing integrated cross-disciplinary capabilities. However, traditional sustainable design curricula often suffer from significant disciplinary silos, overly virtualized practical problem scenarios, and overly simplistic assessment methods, making them ill-suited to meet the evolving needs of talent development. Drawing on constructivism and project-based learning as its theoretical foundations, this study employs research methods—including questionnaire surveys and teaching case studies—to explore reforms in practical sustainable design education through a three-dimensional interdisciplinary framework integrating "Design + Environmental Science + Sociology." The teaching system is restructured across three dimensions: the restructuring of interdisciplinary course modules, shifting teaching objectives toward fostering systemic thinking, and establishing a dual-practice platform comprising "workshops + projects." Building upon this foundation, the study introduces an innovative project-driven teaching approach grounded in real-world challenges, alongside an AI-assisted iterative design teaching model. Practical implementation demonstrates that this approach effectively enhances students' systemic thinking and interdisciplinary collaboration skills, and some of the resulting design solutions have been successfully implemented in real-world contexts; however, it also highlights practical challenges, such as the difficulty of coordinating cross-departmental resources and the uneven disciplinary backgrounds of students. In response, this paper proposes several optimization pathways—namely, establishing a cross-institutional resource-sharing mechanism, reforming a diversified interdisciplinary assessment system, and expanding virtual, digital practice scenarios—aiming to provide a valuable reference for the reform of interdisciplinary practical sustainable design education in China.

Keywords: Interdisciplinary Integration; Sustainable Design; Practical Teaching; Innovative Teaching Methodologies; Cultivation of Innovative Talent.

1. The Contemporary Context of The Multidisciplinary Integration and Sustainable Design Course

1.1. Global Sustainable Development Demands for the Competencies of Design Professionals

The global advancement of sustainable development and dual-carbon strategies has given rise to new competency requirements for sustainable design professionals across society. The United Nations Development Programme's 2023 Global Sustainable Development Talent Report highlights that by 2030, there will be an urgent need for a large number of interdisciplinary sustainable design professionals in fields such as climate action and the circular economy worldwide; in China, the shortage of versatile design professionals exceeds 2 million, and traditional single-disciplinary training models are no longer adequate to meet the practical demands of the industry. [1-2]

In "Design for the Real World", Victor Papanek argues that design should address real-world societal challenges; when translated into terms of talent competencies, this approach encompasses three key aspects: First, designers should possess systemic thinking skills, enabling them to integrate interdisciplinary tools—such as carbon accounting and social research—into their design processes, rather than focusing solely on formal aesthetics; Second, designers should

demonstrate the ability to implement complex issues in practice, serving as bridges that connect research, policy-making, and the public to facilitate the implementation of solutions; Third, designers should possess the capacity for dynamic iterative refinement, continuously adjusting their design outcomes based on actual operational data. These competencies compel design education to break down disciplinary barriers and establish a core direction for the reform of practical teaching in this course.

1.2. Policy Orientation for Interdisciplinary Integration in China's Design Education Reform

The Chinese government has successively issued policy documents, such as the "Overall Plan for Deepening the Reform of Educational Evaluation in the New Era," advocating the dismantling of disciplinary barriers and the cultivation of interdisciplinary innovative talents. According to data from the Ministry of Education, the number of newly established interdisciplinary academic programs across China has grown rapidly, with interdisciplinary design programs accounting for a significant proportion. The reform of design education in China is aligned with national strategies—including the "Dual Carbon" goals and rural revitalization—and embodies Tao Xingzhi's philosophy that "life itself is education, and society itself is a school." This reform promotes the deep integration of design studies with engineering, natural sciences, and sociology, with sustainable

design serving as a key focal point of the transformation.

Institutions such as the Academy of Arts & Design at Tsinghua University and the Guangzhou Academy of Fine Arts took the lead in launching pilot programs, establishing interdisciplinary teaching platforms, integrating life cycle assessment and participatory research into practical courses, and generating a substantial body of teaching outcomes. The essence of this policy orientation lies in addressing the shortcomings of traditional design education—namely, its tendency to "emphasize form over substance and skills over systems"—by implementing the principle of fostering virtue through education, cultivating high-level professionals capable of tackling sustainable development challenges, and aligning with the talent development objectives outlined in China's "Education Modernization 2035" plan. [3-5]

1.3. Current Challenges in The Practical Teaching of Traditional Sustainable Design Courses

Through an analysis of relevant materials during the research process, it was discovered that current practical teaching approaches in sustainable design practice suffer from significant shortcomings. The majority of practical exercises still involve single-disciplinary simulated tasks, while the proportion of real-world interdisciplinary projects remains very low; the instructional content tends to focus primarily on design techniques and the application of eco-friendly materials, yet students generally lack interdisciplinary knowledge—such as carbon footprint calculation and social needs assessment—resulting in designs that often represent merely "pseudo-green innovation" at a visual level, with insufficient feasibility for actual implementation.

Furthermore, the assessment system is overly centralized, primarily relying on instructors' grading without the participation of industry experts or service recipients, and lacks sustainable quantitative evaluation indicators—leading students to place excessive emphasis on superficial outcomes. Students trained under this traditional model neither meet the industry's talent demands nor align with the direction of interdisciplinary integration reform; therefore, there is an urgent need to innovate teaching methodologies.

2. Literature Review and Theoretical Foundations for Multidisciplinary Integrated Sustainable Design Education

2.1. An Overview of The Research Trajectory in Interdisciplinary Design Education Both Domestically and Internationally

In the 1960s, Fuller advocated that design should integrate natural sciences with humanities and social sciences to address complex global challenges, thereby establishing the foundational concept for interdisciplinary design education. During the 1990s, institutions across Europe and North America embarked on systematic reforms; the Harvard Graduate School of Design and the Royal Academy of Arts launched interdisciplinary sustainable design programs, developing mature practical frameworks that have since been adopted by numerous international educational institutions.

Domestic research has evolved through three distinct phases: The period from the late 1990s to 2010 represented

the introductory phase, during which scholars such as Liu Guanzhong introduced Western theoretical frameworks and advocated shifting design practices from "creating objects" to "planning solutions"; from 2011 to 2018, the field entered the local exploration phase, marked by the establishment of interdisciplinary workshops on sustainable urban and rural transformation at several universities; and from 2019 to the present, the field has entered the deepening and expansion phase, with numerous institutions offering interdisciplinary practical courses focused on sustainability within the context of the "New Liberal Arts" initiative, leading to a significant increase in the number of relevant research publications.

Overall, cross-disciplinary teaching approaches have evolved alongside the continuous development of sustainability-related issues; however, existing research predominantly focuses on macro-level frameworks and lacks replicable practical teaching methodologies, while there remains a significant gap in studies dedicated to the localized implementation of these approaches.

2.2. Existing Achievements and Research Gaps in Sustainable Design Practice-Based Teaching

Over 60% of design institutions in China offer sustainable design courses, while nearly 40% of these institutions have explored incorporating interdisciplinary faculty; institutions such as Tsinghua University and the Academy of Arts & Design have already accumulated preliminary practical experience. Current research focuses on discussing teaching objectives and university–industry partnerships, confirming the value of real-world projects in fostering students' sustainable awareness.

However, from a cross-disciplinary integration perspective, several shortcomings remain: First, most interdisciplinary collaborations remain at a superficial level—primarily involving the invitation of external experts to deliver lectures—without being integrated throughout the entire teaching process; the fields of design science, environmental science, and sociology have not been deeply aligned. Second, there is a lack of research on pathways for cultivating systemic thinking, as well as a sustainable evaluation model tailored to interdisciplinary outcomes. Third, there is a lack of scalable solutions for resource coordination and conflict resolution within cross-disciplinary collaboration processes.

2.3. The Core Theoretical Framework for Cross-Disciplinary Integrated Teaching: Constructivism and Project-Based Learning

Constructivist theory posits that knowledge is not the result of one-way transmission by the teacher, but rather the outcome of learners actively constructing meaning within contextual and collaborative discourse. Project-based learning serves as the practical vehicle for implementing constructivist principles in instructional settings; it motivates students to engage in inquiry through real-world, complex problems and enables them to integrate knowledge and develop competencies during the project completion process—both of which provide the foundational theoretical underpinning for this study. [6-9]

Traditional curricula often consist primarily of virtual problem-solving exercises, resulting in fragmented subject knowledge and designs that are detached from real-world

contexts. By reengineering teaching based on two major theoretical frameworks, interdisciplinary teams comprising students from design, environmental science, and sociology disciplines were formed; each discipline leveraged its unique strengths to collaboratively complete authentic projects. Students are no longer merely passive recipients of knowledge but actively construct systematic understanding through collaborative learning. Pilot teaching data indicate that following the reform, student satisfaction with the curriculum, as well as their capacity for systematic thinking and interdisciplinary collaboration, have improved significantly. The teaching implementation adheres to the four key elements of "Contextual Collaborative Dialogue and Meaning Construction," incorporates AI tools to facilitate design iteration, and achieves a complete, project-driven learning cycle.

3. Systematic Reconstruction of Multidisciplinary Integrated Sustainable Design Practice-Based Teaching Framework

3.1. Integration of Interdisciplinary Curriculum Modules: Design + Environmental Science + Sociology

This approach establishes a three-dimensional integrated curriculum framework encompassing design, environmental science, and sociology, thereby transcending the traditional boundaries of design courses—which have historically focused solely on form, aesthetics, and material application. Serving as an integrative hub, the design discipline is responsible for translating requirements into actionable solutions, generating creative concepts, integrating spatial or product design proposals, and producing visual and technical drawings; the environmental science module provides quantitative tools such as Life Cycle Assessment (LCA), carbon footprint calculation, site ecological assessment, and material environmental property analysis; the sociology module covers field research, semi-structured interviews, stakeholder identification, and community inclusivity analysis, thereby addressing the socio-humanistic dimension of sustainable design. These three modules form a closed-loop system that is mutually constraining and complementary, effectively overcoming the common flaw in traditional teaching practices—where emphasis is placed on form at the expense of scientific rigor, and on technical specifications at the expense of social appropriateness. [10-13]

In alignment with the UNESCO 2023 Global Framework for Sustainable Development Education Professional Curricula, this course positions environmental quantitative assessment as a prerequisite constraint for scheme conception, rather than as an add-on step applied only after the design has been finalized. This means that during the sketching and conceptualization phase, students should simultaneously conduct preliminary assessments of material carbon emissions and resource recycling potential, thereby avoiding the practice of "first creating an aesthetically pleasing design and then adding environmental justification" – a form of pseudo-sustainable design. For example, in a practical task involving the revitalization of community public spaces, design students cannot proceed directly to spatial form creation; instead, they must apply knowledge from the field of environmental science to understand the site's

microclimate and perform assessments of the protection of native vegetation; simultaneously, they should conduct interviews with users across different age groups, document community cultural practices, and investigate the cost affordability of low-income groups. The final proposed solution must simultaneously meet multiple criteria: functional aesthetics, low-carbon quantitative indicators, alignment with community culture, and economic feasibility.

The "Sustainable Design" course in the Product Design program at Jingdezhen Ceramic University is structured over a total of 64 credit hours. The allocation of these hours balances theoretical instruction with practical training: 16 hours are dedicated to sustainable design methodology and design innovation training, another 16 hours are devoted to hands-on instruction on sociological fieldwork methods, and the remaining hours are entirely used for guiding interdisciplinary group collaboration practices. During the theoretical teaching phase, instead of having instructors from different disciplines deliver lectures independently, a collaborative teaching approach is adopted—where the same teaching case is interpreted from various disciplinary perspectives by instructors representing different fields. This approach helps students develop a habit of thinking across multiple dimensions and lays a solid knowledge foundation for the subsequent practical components.

3.2. Updated Practical Teaching Objectives: From Skill Training to Systematic Thinking Development

Traditional sustainable design practice-based teaching approaches have long placed greater emphasis on explicit skills—such as software modeling, rendering, and hand-drawing—while assigning an extremely low weight to the assessment of higher-order competencies, including problem analysis, multi-factor trade-offs, and practical feasibility. Although students may produce drawings with visually appealing designs, they often fail to account for implicit constraints—such as carbon emissions, operational and maintenance costs, or conflicts of public interest—during the entire product lifecycle—from conception to disposal. As a result, their designs may look attractive but prove impossible to implement in real-world practice.

Building upon constructivist learning theory, this study shifts the core objective of practical teaching from mere skill training to the hierarchical cultivation of systemic thinking. It introduces the Systemic Thinking Iceberg Model to delineate three-tiered competency gradients: the Base Layer, which focuses on retaining essential foundational design skills—such as design expression and drawing production—to ensure that students possess the ability to visually present their design outcomes; the Integration Layer, which emphasizes the development of interdisciplinary knowledge integration capabilities, requiring students to understand and assimilate data and research findings derived from environmental science and sociology, and to transform them into design constraints and design opportunities; and the Advanced Layer, which aims to foster the ability to analyze and solve complex system-based problems, guiding students to identify the interrelationships among the internal environmental, economic, and social factors of a project, weigh competing interests, and develop comprehensive optimal solutions.

Taking the design of household reusable storage products as an example, under the new educational objectives, students are no longer expected to merely complete the design of

product appearance and structural form. Systemic thinking requires students to simultaneously master a range of information—including plastic material recycling technical standards, the disassembly and recycling processes after product disposal, household users' storage and usage habits, subsequent refurbishment and maintenance requirements, and mass-production costs—while balancing the competing priorities of environmental benefits, user experience, and production and operational costs. When applied to practical sustainable product design projects, the course no longer treats the visual appeal of rendered graphics as the primary evaluation criterion; instead, it requires students to complete the entire workflow, encompassing market and user data research, stakeholder interviews, comparative analysis of multiple design solutions, and a full life-cycle feasibility assessment. Through this process, students are trained to move beyond the narrow perspective of a single designer and understand that sustainable product design is not about pursuing the absolute optimum for a single metric, but about achieving a comprehensive balance among multiple objectives—namely, enhancing material recyclability, improving the user experience, and ensuring viable conditions for industrial-scale implementation—thereby fostering versatile design professionals who meet societal needs.

3.3. Establishing Diversified Practical Teaching Platforms: Workshops + Industry–University Joint Projects

Relying solely on classroom-based instruction is insufficient for fostering systematic thinking and interdisciplinary collaboration skills; therefore, this study employs a dual-practice approach—comprising interdisciplinary thematic workshops and real-world industry-academia collaborative projects—to bridge the gap between classroom theoretical learning and actual societal demands, thereby putting into practice Tao Xingzhi's educational philosophy that "action is the beginning of knowledge, and knowledge is the culmination of action."

Interdisciplinary thematic workshops represent a short-term, high-intensity practical learning format that transcends departmental administrative boundaries and enables the flexible formation of cross-disciplinary learning teams. Taking the "Innovative Design of Recyclable Household Products" workshop as an example, the overall workshop duration is four weeks, divided into three distinct phases:

- ****Week 1:**** Interdisciplinary collaborative field research – students jointly engage in household environments and manufacturing facilities to conduct user observation interviews and collect data on production processes and materials;
- ****Week 2:**** Multidisciplinary co-creation of product solutions – within each group, participants engage in divergent thinking based on the issues identified during the field research; students focus on addressing constraints related to the full lifecycle carbon emissions and recycling performance of materials, while simultaneously aligning their designs with the actual usage needs and purchasing power of household users before finalizing the product proposal;
- ****Week 3:**** Continuous refinement of product prototypes and internal cross-disciplinary peer review;
- ****Week 4:**** Presentation of outcomes and post-workshop reflection/optimization session conducted for corporate R&D representatives and industry mentors. The workshop incorporates a multi-mentor guidance system, with instructors specializing in product design, environmental art design, and

sociology jointly participating in group mentoring to promptly address any misconceptions stemming from single-disciplinary thinking among students. Based on the research data, such workshops significantly enhance students' systematic understanding of sustainable design—with the degree of improvement being markedly higher than that achieved through conventional classroom teaching.

These two types of implementation vehicles form a progressive and complementary practical chain: interdisciplinary workshops focus on breaking down disciplinary silos, facilitating the integration of cross-disciplinary knowledge, and cultivating systematic thinking skills; meanwhile, university–industry joint projects take the creative outcomes generated by these workshops and refine them through iterative development under the practical constraints of industry, policy, and fiscal realities, thereby verifying the actual feasibility of these solutions. Survey data indicate that institutions adopting the dual-vehicle model achieve significantly higher rates of practical application and job placement alignment for student outcomes compared to those using a single classroom-based teaching model, thereby providing actionable support for system restructuring.

4. Multidisciplinary Integration in Sustainable Design Practice-Based Teaching Methods – Innovative Design

4.1. Project-Based Teaching Methodology Design Based on Real-World Issues

The project-based teaching approach, grounded in real-world issues, represents a core solution to the challenges inherent in traditional practical teaching methods. Aligning with John Dewey's educational philosophy—that "education is the reorganization and transformation of experience"—this approach completely discards simplified, virtual problem statements; instead, all practical project topics are derived from real-world scenarios such as community revitalization, rural revitalization, and the development of green products by enterprises. Real-world issues inherently involve multiple conflicting constraints; for example, a project aimed at developing reusable household products must simultaneously address practical challenges—including material recyclability requirements, upper limits on mass-production costs, conflicting usage needs among different households, and limitations imposed by existing manufacturing processes—resources that cannot be replicated through virtual problem-based tasks.

During the project launch phase, a "Stakeholders in the Classroom" mechanism is implemented, inviting R&D engineers, production process technicians, carbon accounting researchers from home furnishing enterprises, and representatives from ordinary household users to participate in classroom sessions. These participants provide comprehensive introductions to the project's background, mass-production cost boundaries, practical process limitations, as well as the usage and commercial objectives of each stakeholder, enabling students to engage directly with real-world decision-making scenarios from the very beginning of the course—rather than engaging in idealized conceptual work within a closed classroom setting. The teaching process is structured into five consecutive phases: issue decomposition, interdisciplinary research, solution

prototyping, stakeholder feedback, and multiple rounds of solution iteration; each phase specifies clear interdisciplinary collaboration milestones and includes scheduled periodic reporting sessions.

The group maintains a clear division of labor while emphasizing full-staff participation across the entire project lifecycle to avoid fragmented task allocation: students majoring in Product Design lead the visualization of product form, functional structure, and design solutions, and participate in user research as well as discussions on carbon metrics; students majoring in Environmental Art Design are responsible for using Life Cycle Assessment (LCA) tools to calculate the full-life-cycle carbon emissions and material resource consumption of various design solutions, while also understanding the practical conditions required for the mass production of these products; all students are required to conduct household user interviews, identify user needs, and detect potential conflicts, and to translate their research findings into clear design insights rather than merely producing a research report. The group holds regular weekly joint workshops to synchronize their respective progress and collaboratively resolve any project-related conflicts.

In this case study on the design of household reusable storage products, the initial all-recycled bio-based plastic one-piece molding solution proposed by the students demonstrated outstanding carbon reduction performance; however, its raw material cost exceeded the budget allocated for conventional materials. Under the guidance of industry experts, the interdisciplinary team conducted a renewed comparison of various materials and manufacturing processes, ultimately adopting a hybrid approach that utilizes recycled PP plastic as the primary material paired with a small number of disassemblable virgin plastic components. This approach not only met the product's carbon reduction targets throughout its entire life cycle but also reduced the overall production cost; the solution was well-received by both the R&D team and the household users who participated in the testing phase. Statistical data from three rounds of teaching practice indicated that, after implementing this teaching methodology, the vast majority of students understood that sustainable product design is not merely about visual form innovation, but involves balancing multiple environmental, social, and economic objectives; the effectiveness of this teaching method was significantly superior to that of traditional instructional approaches.

4.2. AI-aided Sustainable Design Solution Iterative Teaching Application

Design scholar Monkley argues that contemporary design no longer focuses on a single act of creative output, but rather on a dynamic optimization process oriented toward complex systems. Traditional practical teaching approaches rely on the manual expertise of both teachers and students to refine design proposals; however, the processes involved in carbon accounting and environmental impact assessment calculations are cumbersome, the number of iterative cycles is limited, and students find it challenging to intuitively understand the differing environmental benefits arising from various design choices. The introduction of artificial intelligence tools offers a novel iterative pathway for interdisciplinary practical teaching.

AI can be integrated with a full life cycle assessment database to rapidly perform quantitative calculations of a product's carbon emissions, material consumption, and

environmental impacts. In a teaching practice focused on designing reusable household products, students using an AI-based carbon accounting tool were able to complete the work typically required in 14 days under traditional methods in just 3 days. They conducted a comparative analysis of the environmental benefits of more than a dozen alternative product designs, enabling them to visually observe how changes in base material selection, structural disassembly approaches, or manufacturing processes affect carbon emission levels. This approach helps students develop a quantitative mindset toward sustainability, rather than relying on a superficial understanding such as "using recycled materials automatically means being sustainable."

In multidisciplinary team collaboration, artificial intelligence also serves as an intermediary for integrating cross-disciplinary information. The design discipline contributes visual creativity, environmental science provides environmental constraint parameters, and sociology supplies user preference weights; these fragmented inputs from different disciplines are fed into generative design tools, where algorithms automatically generate multiple alternative solutions, which are then submitted to the interdisciplinary team for manual screening, evaluation, and refinement. AI handles the computationally intensive tasks and solution generation, while students retain full control over their creative decision-making process, preventing technological tools from replacing students' independent thinking.

The comprehensive teaching cycle is structured as follows: Initial solution development → Quantitative AI-assisted assessment of environmental and social indicators → Interdisciplinary group discussions to identify optimization directions → AI-generated multiple iterative candidate solutions → Joint evaluation and screening by multidisciplinary teachers and stakeholders. Throughout this iterative process, students continuously refine their product concepts by integrating carbon emission calculation data and feedback from household user surveys, actively constructing interdisciplinary knowledge within practical contexts. Teaching practice data demonstrate that, following the implementation of this instructional component, both the environmental compliance and user need alignment of students' product solutions have improved significantly. The AI-assisted iterative approach does not replace traditional teacher-led instruction or field-based user research; rather, it frees students from the burden of repetitive environmental calculation tasks, enabling them to devote more of their energy to developing higher-order competencies—such as problem analysis, multi-stakeholder trade-off analysis, and product concept decision-making—thereby facilitating the achievement of the systematic thinking development objective.

5. Case Study Implementation of Multidisciplinary Integrated Sustainable Design Practice-Based Teaching

5.1. Implementation of Interdisciplinary Teaching in the Corn Kernel Smart Recycling Machine (Circorn) Product Development Project

This practical case study focuses on the design of an intelligent corn cob recycling machine tailored for rural areas

in mountainous regions, conducting an interdisciplinary product design practice aimed at addressing real-world challenges such as the waste of corn cob resources in China's mountainous areas and the scarcity of toys and learning materials among rural children. Grounded in authentic rural social contexts, the project centers on the circular reuse of agricultural waste by integrating agricultural resource recycling, rural societal needs, and 3D printing product development into a cohesive approach. It serves as a typical sustainable design education initiative that seamlessly combines environmental science, sociology, and product design.

Interdisciplinary project teams were formed based on the ratio of "Product Design students + Environmental Design students + Sociology students," with each team fully implementing a project-driven teaching methodology. In the preliminary phase of the project, Sociology students led rural field research, conducting semi-structured interviews with farmers, rural children, and local grassroots administrators in mountainous areas, collecting questionnaire data to analyze the current status of corn cob waste disposal practices, the actual needs of children's products, as well as the conditions for rural equipment operation and maintenance and the local cost affordability; Environmental Science students conducted research on the physicochemical properties of corn cobs, performed a Life Cycle Assessment (LCA) analysis covering the entire lifecycle of corn cob material—after being crushed and modified into 3D printing granules—and established baseline carbon emission data for the material, clarifying the energy consumption, pollution, and circularity constraints associated with its processing; Product Design students participated throughout the entire fieldwork process,

documenting the rural usage environment, equipment mobility scenarios, and user operational pain points, thereby ensuring that all conceptual designs remained grounded in real-world conditions.

During the solution design phase, each team is required to simultaneously complete the carbon emission accounting for the materials used and the validation of user requirements for every round of product concept sketches; this enables the rapid comparison of the varying environmental benefits arising from different product structures, materials, and manufacturing processes using an AI-powered carbon accounting tool. A multidisciplinary mentorship team provides joint guidance, helping to refine the solutions from three perspectives—product implementation processes, resource recycling benefits, and suitability for rural communities—thereby preventing the solutions from falling into the trap of being driven solely by aesthetic innovation or an exclusive focus on material and technical specifications.

The final product is the Circorn "Xunxin" Corn Cob Smart Recycling Machine – a comprehensive product solution that integrates corn cob threshing and crushing, pellet modification, and 3D printing capabilities into a single system. This equipment enables the on-site conversion of agricultural waste into children's toys and educational materials, while addressing the requirements of mobile operation capabilities, material recycling benefits, and rural maintenance cost constraints. This solution fully demonstrates the feasibility of collaboratively driving sustainable product innovation through the integration of design science, environmental science, and sociology, serving as a practical example for rural sustainable product design education.



Fig 1. Intelligent Recycled Machine for Corn Husk in the Context of Resource Circulation

5.2. Record of Collaborative Processes and Outcome Delivery among Students from Different Disciplines

This teaching case involved 34 students from diverse academic backgrounds, who were organized into multiple interdisciplinary teams. Interdisciplinary collaboration did not simply entail assembling students from different disciplines to complete assignments; rather, it involved clearly defining the input points, communication mechanisms, and output deliverables for each discipline, establishing a regular weekly joint discussion session, and creating an online shared document platform to centrally consolidate survey and interview records, material estimation reports, and product sketch prototypes—thereby ensuring seamless interdisciplinary information exchange.

During the project initiation phase, students prioritize conducting field research in rural areas to identify the actual needs of farmers and rural children, as well as to uncover social constraints—such as the barriers to operating rural equipment and the human resource requirements for subsequent operation and maintenance—that are often overlooked by design and environmental engineering disciplines; in the second phase, they carry out an environmental impact assessment for the recycling of corn cob waste and produce a report detailing carbon emission and energy consumption data, thereby establishing quantifiable circular economy benefit targets for the product; subsequently, based on the research data, the students develop the product's form factor, structure, human-machine interaction, and APP control system design, transforming societal demands and environmental constraints into specific product design requirements. [14-15]

The mid-phase of collaboration represents a stage where conflicts become particularly acute; some teams encountered challenges such as products featuring avant-garde exterior designs but with excessively high material processing energy consumption, or products with excellent lifecycle performance metrics but complex equipment operation that did not align with the capabilities of rural users. Subsequently, these teams conducted multiple rounds of collaborative negotiations, re-evaluated the energy consumption data for modified manufacturing processes, iteratively optimized the product design and overall machine structure, and sought a comprehensive optimal solution under multiple constraints.

Each group ultimately produced a comprehensive smart product redesign design proposal, which includes the product's exterior design, exploded views of the internal mechanisms, the resource recycling process flowchart, the human-machine interaction and APP system, and exhibition boards showcasing diverse rural application scenarios. Interdisciplinary collaboration effectively mitigated three common challenges: product designs that focused solely on visual appeal without a scientific basis for circular design; environmental science-based solutions with ideal technical specifications but inadequate consideration of actual rural usage conditions; and sociological research that offered valuable social insights but lacked tangible product embodiments for real-world implementation. The complementary integration of knowledge from various disciplines yielded design outcomes that balance environmental circularity benefits, rural social compatibility, and industrial feasibility, establishing a replicable,

interdisciplinary teaching practice model for sustainable product development.

6. Effectiveness Evaluation and Analysis of Multidisciplinary Integrated Practical Teaching

6.1. Analysis of Teaching Satisfaction and Competence Enhancement Based on Student Feedback

This study involved 36 product design students participating in a real-world project, utilizing a five-point Likert scale combined with semi-structured interviews for data collection; the valid questionnaire response rate was 96.5%. The overall course satisfaction score was 4.62/5, with the vast majority of students expressing approval of the authentic project and the interdisciplinary collaboration component; however, a small number of respondents highlighted that the cost of acquiring cross-disciplinary knowledge was relatively high.

When comparing self-assessment data before and after the course implementation, students' scores in systematic thinking, interdisciplinary collaboration, and project implementation capabilities all showed significant improvement. Students also demonstrated enhanced proficiency in sustainable thinking, the ability to translate design concepts into practical applications, and the skill of interpreting research findings. The most frequently used positive terms included "real-world problems" and "interdisciplinary synergy"; negative feedback primarily centered on "class schedule conflicts" and "high communication costs," providing empirical evidence for future teaching optimization.

6.2. Summary of the Strengths and Weaknesses in the Implementation of the Current Teaching Program

Key advantages: First, the real-world problem-based project approach effectively fosters students' systematic understanding and ensures that teaching outcomes are applied in practical contexts; second, AI-powered iterative refinement significantly reduces the time required for quantitative analysis, thereby enhancing teaching efficiency.

Current limitations: First, the curriculum needs to integrate multidisciplinary knowledge—from fields such as environmental science and sociology—which involves inviting faculty members from various departments, coordinating teaching content, and incurring high resource coordination costs; moreover, scheduling lectures delivered by external instructors alongside the core curriculum's own schedule is complex, and some students are unable to fully participate in all the multidisciplinary thematic teaching sessions due to time conflicts; Second, the assessment system has not been fully reformed—although the teaching approach incorporates numerous interdisciplinary evaluation dimensions, the final assessments still tend to favor visual outcomes such as product designs and renderings, making it difficult to accurately quantify students' contributions to interdisciplinary competencies—such as the use of carbon accounting tools or the analysis of user societal needs; Third, there are significant disparities in students' foundational disciplinary backgrounds: product design students often lack

prior knowledge in environmental science or sociology; furthermore, the limited instructional time allocated to the prerequisite multidisciplinary foundational courses forces students to devote substantial time in the early stages of group projects to align concepts and fill gaps in foundational theory, thereby compressing the time available for refining and iterating product solutions.

7. Optimal Approaches to Optimizing Multidisciplinary Integrated Sustainable Design Practice-Based Teaching

7.1. Establishment of a Cross-University and Cross-Professional Teaching Resource Sharing Mechanism

Many institutions, constrained by their respective disciplinary structures, lack teaching resources such as carbon accounting laboratories or design transformation platforms. By leveraging the Regional Higher Education Alliance to establish a sharing mechanism, this approach encompasses three key components: first, co-building a cross-institutional faculty database to facilitate cross-university course selection and credit transfer, thereby addressing gaps in the institution's own curriculum; second, opening up laboratories, practical training bases, and university-industry collaboration projects to create a resource compensation mechanism that reduces redundant facility development; and third, establishing a unified information platform to dynamically publish projects, faculty members, and resources, thereby matching supply with demand. The experience gained from implementing this regional alliance demonstrates that such a sharing mechanism can enrich the teaching offering and alleviate the resource constraints faced by individual institutions.

7.2. Reform of a Diversified Assessment and Evaluation System Tailored for Cross-Disciplinary Teaching

Reform the existing assessment model, which was solely based on evaluations conducted by design instructors with an overemphasis on aesthetic outcomes. Redesign the assessment framework: regarding assessment entities, implement a combination of peer assessments conducted by interdisciplinary faculty, collaborating partners, and students; regarding assessment dimensions, establish a three-dimensional evaluation model encompassing the feasibility of design innovation, quantitative indicators of environmental sustainability, and the degree of alignment with societal needs—with balanced weights assigned to each dimension; regarding assessment phases, increase the weight of formative assessment—allocating 60% to process-based evaluation and 40% to final deliverables. Establish differentiated assessment indicators tailored to various disciplines: for design programs, focus on the integration and implementation of design solutions; for Environmental Science programs, emphasize the scientific rigor of quantitative analysis; for Sociology programs, prioritize the evaluation of research effectiveness and stakeholder coordination outcomes. This approach aims to prevent the phenomenon of "design-dominated, with other disciplines marginalized," using the assessment reform as a means to positively guide students in developing systematic thinking skills.

7.3. Future-Oriented Sustainable Design Practice Teaching Development Outlook

Against the backdrop of carbon neutrality, the demand for sustainable design professionals continues to grow. Future education will embrace broader access to resources; virtual simulation and metaverse-based practice platforms will overcome geographical barriers, enabling students from diverse locations to collaborate on real-world projects. Drawing on the Competency-Based Education (CBET) approach, teaching will shift further from knowledge transmission to competency development. Artificial intelligence will be deeply integrated into every stage of the teaching process, supporting quantitative analysis and the generation of multiple solutions. Efforts will be sustained to foster deep interdisciplinary integration, cultivating versatile design professionals to contribute to sustainable development both nationally and globally.

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