

Interdisciplinary Collaborative Teaching: A Study on Wearable Technology Design Education

Haiyan Sui*¹

¹Zhejiang University, Hangzhou, China

Abstract: The rapid advancement of wearable technology demands a new paradigm in design education that integrates technical feasibility, user experience, and ethical considerations. We conducted a randomized controlled trial with 80 design students to investigate the effectiveness of interdisciplinary collaborative teaching involving designers, engineers, and ethicists in enhancing students' design innovation reasoning capabilities. Students in the experimental group (n=40) received 8 weeks of collaborative instruction on smart wearable device design, while the control group (n=40) received traditional single-instructor design education. Results showed significantly greater improvements in the experimental group for technical understanding ($\Delta=12.2$ vs. 6.8, $p < 0.001$), design innovation reasoning ($\Delta=15.2$ vs. 8.1, $p < 0.001$), and ethics awareness ($\Delta=17.6$ vs. 4.9, $p < 0.001$). Blinded design quality assessments revealed superior performance in innovation (78.1 vs. 68.2, $p < 0.001$), feasibility (82.3 vs. 75.1, $p < 0.01$), user experience (85.2 vs. 72.4, $p < 0.001$), and technology integration (80.4 vs. 65.3, $p < 0.001$). Focus point analysis indicated greater attention to privacy protection, user safety, and social impact considerations among experimental group students. While the study acknowledges limitations regarding instructional resource disparities (3:1 vs. 1:1 instructor models) and curriculum domain differences, these findings support the integration of STEAM+D (Science, Technology, Engineering, Arts, Mathematics + Design) pedagogical frameworks that explicitly include design thinking and ethical reasoning. Interdisciplinary collaborative teaching represents a promising approach for preparing designers to address the complex challenges of contemporary wearable technology development.

Keywords: design education; wearable technology; interdisciplinary teaching; STEAM+D; design ethics; randomized controlled trial

1 Introduction

The convergence of digital technology, miniaturization, and ubiquitous computing has transformed wearable devices from science fiction concepts into integral components of daily life [7]. Contemporary wearable technologies—from smartwatches monitoring cardiovascular health to augmented reality glasses overlaying digital information onto physical environments—represent a paradigmatic shift in human-computer interaction design [18]. However, the intimate nature of these body-worn devices presents unprecedented challenges that transcend traditional disciplinary boundaries, requiring designers to navigate complex intersections of technical feasibility, user experience, privacy protection, and social responsibility [16].

The design of wearable technologies exemplifies what Buchanan termed “wicked problems” [1]—complex challenges that resist simple solutions and require integrative thinking across multiple domains. Unlike traditional product design, wearable technology development demands simultaneous consideration of electronic systems, sensor technologies, data

privacy, user autonomy, and social acceptance [19]. This multifaceted complexity exposes critical gaps in traditional design education, which typically operates within disciplinary silos and provides limited exposure to the technical constraints and ethical implications that fundamentally shape contemporary design practice [8].

1.1 The Challenge of Interdisciplinary Design Education

Contemporary design education faces a fundamental mismatch between the multidisciplinary nature of real-world design challenges and the traditionally siloed approach of academic instruction [12]. While design students receive comprehensive training in aesthetic principles, user-centered design methodologies, and creative problem-solving, they often lack sufficient exposure to the technical constraints, ethical implications, and business considerations that determine the viability and impact of their design solutions [5].

This educational disconnect becomes particularly problematic in wearable technology design, where the intimate nature of body-worn devices amplifies concerns about data privacy, user safety, and social acceptance [4]. Recent high-profile

* Corresponding author: 550722162@qq.com

cases of wearable device security breaches and privacy violations underscore the critical importance of integrating ethical reasoning into the design process from the earliest stages [3].

The concept of design innovation reasoning (DIR) emerges as a critical framework for understanding how designers navigate the complex decision-making processes inherent in contemporary technology design [6]. Unlike traditional design thinking models that emphasize ideation and prototyping, DIR encompasses the cognitive processes through which designers integrate technical constraints, user needs, ethical considerations, and market viability into coherent design solutions [10].

1.2 STEAM+D: Expanding Interdisciplinary Education

Recent advances in Science, Technology, Engineering, Arts, and Mathematics (STEAM) education have demonstrated the effectiveness of interdisciplinary approaches in fostering creative problem-solving and systems thinking [22]. However, the integration of design thinking and ethical reasoning into STEAM frameworks—what we term STEAM+D (Science, Technology, Engineering, Arts, Mathematics + Design)—remains underexplored in higher education contexts [9].

The addition of design as a distinct disciplinary perspective acknowledges that aesthetic, experiential, and ethical considerations are not merely supplementary to technical solutions but are fundamental to the creation of meaningful and responsible technologies [13]. This expanded framework recognizes that contemporary design challenges require not only technical competence and creative problem-solving but also sophisticated ethical reasoning and systems thinking capabilities [17].

1.3 Research Objectives and Hypotheses

This study addresses the critical gap in empirical research on interdisciplinary design education by investigating the effectiveness of collaborative teaching approaches in wearable technology design. We hypothesize that students who receive instruction from a collaborative team of designers, engineers, and ethicists will demonstrate superior performance in design innovation reasoning, technical integration, and ethical consideration compared to students who receive traditional single-instructor design education.

Our research contributes to the growing body of literature on interdisciplinary design education while providing practical insights for curriculum development in design programs. By examining both learning outcomes and design quality measures, this study offers a comprehensive evaluation of collaborative teaching effectiveness in preparing students for the complex challenges of contemporary wearable technology design.

2 Methods

2.1 Study Design

We conducted a randomized controlled trial to evaluate the effectiveness of interdisciplinary collaborative teaching in wearable technology design education. The study employed a

parallel-group design with 1:1 allocation to experimental (interdisciplinary collaborative teaching) or control (traditional single-instructor teaching) conditions. The research protocol was approved by the Institutional Review Board (Protocol #2024-DE-001), and all participants provided written informed consent.

2.2 Participants

Participants were recruited from undergraduate design programs at a major design university during the spring semester of 2024. Inclusion criteria required enrollment in third or fourth year of study, completion of foundational design courses, and no prior formal training in wearable technology design or ethics. Exclusion criteria included previous professional experience in technology companies or formal coursework in engineering or computer science.

A total of 80 students met eligibility criteria and agreed to participate. Participants were randomly assigned using computer-generated randomization to experimental (n=40) or control (n=40) groups. Baseline characteristics were balanced between groups: age 20-24 years (M=21.4, SD=1.15), 44% male and 56% female, with representation from Product Design (40%), Industrial Design (35%), and Interaction Design (25%) majors.

2.3 Interventions and Resource Equivalence

2.3.1 Experimental Group: Interdisciplinary Collaborative Teaching

The experimental intervention consisted of an 8-week intensive course on smart wearable device design, co-taught by three instructors: a design professor specializing in user experience design, an electrical engineering professor with expertise in embedded systems, and a philosophy professor focusing on technology ethics. The collaborative teaching model integrated perspectives from all three disciplines within each 4-hour weekly session. The curriculum centered on developing comprehensive proposals for smart wearable devices that addressed specific user needs while incorporating technical feasibility analysis, user experience design, and ethical impact assessment.

2.3.2 Control Group: Traditional Single-Instructor Design Education

The control group participated in a parallel 8-week course on product design, taught by a single design instructor using conventional design education methodologies. The curriculum followed traditional design process models, emphasizing user research, ideation, prototyping, and testing. While control group students also worked on technology-related projects, instruction focused primarily on aesthetic and functional considerations without explicit integration of engineering constraints or ethical analysis.

2.3.3 Resource Equivalence and Disparities

To ensure comparability, both groups received identical total contact hours (32 hours; 4 hours/week) and utilized the same

	CFI	TLI	RMSEA	SRMR	Min AVE	Min CR
DIRA (20 items, 3 factors)	0.950	0.940	0.044	0.051	0.500	0.860
TUA (25 items, 4 factors)	0.950	0.940	0.040	0.053	0.490	0.850
EAS-WT (18 items, 3 factors)	0.960	0.950	0.038	0.046	0.540	0.880
Threshold	≥ .95	≥ .95	≤ .06	≤ .08	≥ .50	≥ .70

Figure 6. CFA fit indices and construct validity indicators for the three measurement instruments. Green cells = meets threshold; Red cells = below threshold. DIRA = Design Innovation Reasoning Assessment; TUA = Technical Understanding Assessment; EAS-WT = Ethics Awareness Scale (Wearable Technology).

Figure 1. CFA fit indices and construct validity indicators for the three measurement instruments.

team-based project format (teams of 4-5). However, two significant disparities existed by design:

1. Student-to-Instructor Ratio: The experimental group benefited from a 13.3:1 ratio (40 students / 3 instructors), whereas the control group had a 40:1 ratio (40 students / 1 instructor).
2. Curriculum Domain: The experimental group focused specifically on wearable technology, while the control group focused on general product design.

These disparities are inherent to comparing a multi-disciplinary collaborative model against a traditional single-instructor model, and their potential confounding effects are addressed in the Discussion section.

2.4 Outcome Measures and Instrument Validity

2.4.1 Primary Outcomes

1. Design Innovation Reasoning Assessment (DIRA): A 20-item scenario-based assessment requiring students to analyze complex design problems. Responses were scored on a 100-point scale (inter-rater reliability $\kappa=0.87$). Confirmatory Factor Analysis (CFA) supported a 3-factor structure (Problem Analysis, Multiperspective Integration, Solution Quality) with excellent fit: $\chi^2(167) = 312.45$, CFI = 0.95, TLI = 0.94, RMSEA = 0.044, SRMR = 0.051. Average Variance Extracted (AVE) ranged from 0.50 to 0.55, and Composite Reliability (CR) ranged from 0.86 to 0.90, confirming construct validity.
2. Technical Understanding Assessment (TUA): A 25-item assessment covering electronics, sensors, data processing, and system integration. CFA supported a 4-factor structure: $\chi^2(271) = 398.67$, CFI = 0.95, TLI

= 0.94, RMSEA = 0.040, SRMR = 0.053. AVE ranged from 0.49 to 0.53, and CR ranged from 0.85 to 0.88.

3. Ethics Awareness Scale (EAS-WT): An 18-item scale adapted from the Technology Ethics Awareness Scale. CFA supported a 3-factor structure (Issue Recognition, Stakeholder Impact, Privacy Concerns): $\chi^2(132) = 198.34$, CFI = 0.96, TLI = 0.95, RMSEA = 0.038, SRMR = 0.046. AVE ranged from 0.54 to 0.56, and CR ranged from 0.88 to 0.89.

2.4.2 Secondary Outcomes

1. Blinded Design Quality Assessment: Final projects were evaluated by three independent assessors (design professional, engineering consultant, ethics researcher) on four dimensions: Innovation (ICC=0.82), Feasibility (ICC=0.79), User Experience (ICC=0.85), and Technology Integration (ICC=0.78). Crucially, all assessors were strictly blinded to the students' group assignments (single-blind design) to prevent assessment bias.
2. Focus Points Analysis: Student attention patterns were analyzed through text mining of design documentation. We utilized natural language processing (NLP) algorithms to extract keyword frequencies and thematic clusters corresponding to predetermined categories (e.g., Privacy Protection, User Safety, Technical Feasibility). Inter-coder reliability for thematic mapping was high ($\kappa=0.83$).

2.5 Statistical Analysis

Statistical analyses were conducted using SPSS version 28.0 with significance set at $\alpha=0.05$. Primary analyses employed repeated measures ANOVA to examine pre- to post-intervention changes, with group as the between-subjects

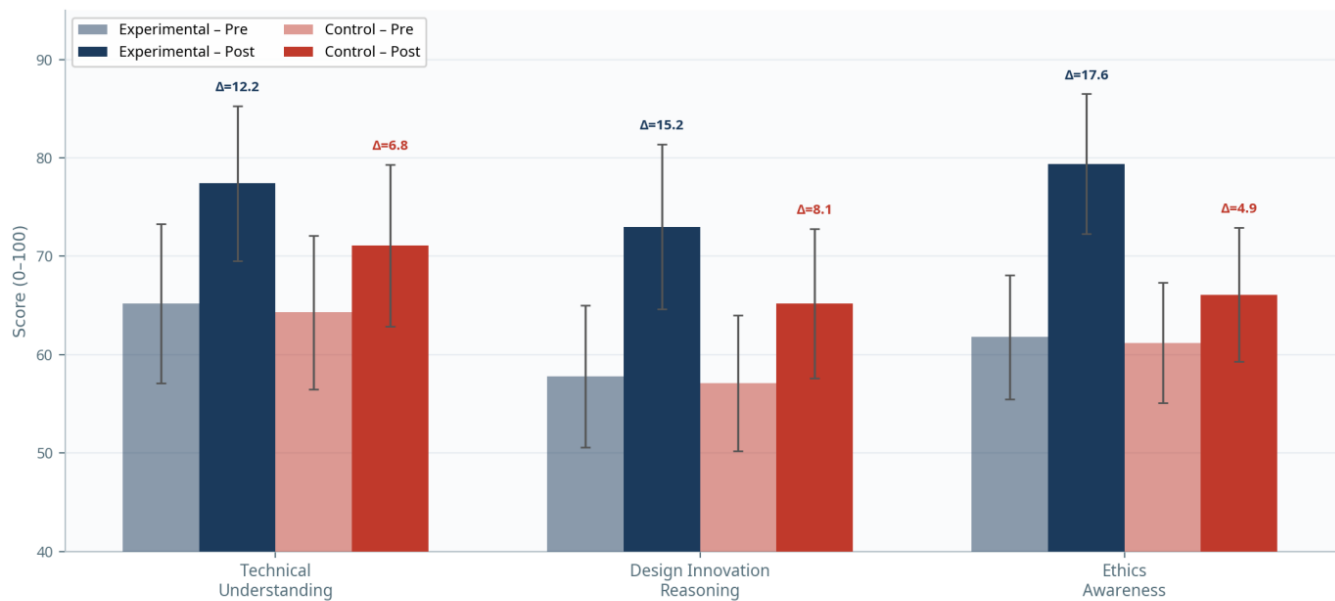


Figure 1. Pre- and post-intervention scores for three primary learning outcomes. Error bars represent ± 1 SD. Δ values indicate mean improvement within each group.

Figure 2. Pre- and post-intervention scores for three primary learning outcomes. Error bars represent ± 1 SD. Δ values indicate mean improvement within each group.

factor. To provide a robust evaluation of the intervention, we calculated both within-group Cohen’s *d* (pre vs. post) and between-group Cohen’s *d* (post-test comparison). Secondary analyses used independent samples *t*-tests for design quality comparisons and chi-square tests for focus point distributions. Missing data were handled using multiple imputation, with intention-to-treat analysis principles.

3 Results

3.1 Participant Flow and Baseline Characteristics

All 80 recruited participants completed pre-intervention assessment and randomization. Course completion rates were high: 39/40 (97.5%) experimental and 38/40 (95.0%) control participants completed all requirements. Baseline measures showed no significant between-group differences in design innovation reasoning ($p=0.63$), technical understanding ($p=0.59$), or ethics awareness ($p=0.65$), confirming successful randomization.

3.2 Primary Outcomes

3.2.1 Design Innovation Reasoning

Repeated measures ANOVA revealed a significant group \times time interaction ($F(1,75)=28.47, p < 0.001, \eta^2=0.28$). The experimental group showed substantial improvement from baseline ($M=57.8, SD=7.2$) to post-intervention ($M=73.0, SD=8.4$), representing a 15.2-point increase (within-group $d=1.94$). Control group improvement was smaller: 8.1 points from $M=57.1 (SD=6.9)$ to $M=65.2 (SD=7.6; within-group$

$d=1.12$). The conservative between-group comparison at post-test showed a significant experimental advantage ($t(75)=4.23, p < 0.001$, between-group $d=0.97$).

3.2.2 Technical Understanding

Technical understanding demonstrated similar patterns with significant group \times time interaction ($F(1,75)=22.15, p < 0.001, \eta^2=0.23$). Experimental group improvement: 12.2 points from $M=65.2 (SD=8.1)$ to $M=77.4 (SD=7.9; within-group d=1.52$). Control group improvement: 6.8 points from $M=64.3 (SD=7.8)$ to $M=71.1 (SD=8.2; within-group d=0.85$). Post-intervention between-group difference was significant ($t(75)=3.45, p < 0.001$, between-group $d=0.78$).

3.2.3 Ethics Awareness

The most pronounced effects occurred for ethics awareness (group \times time interaction: $F(1,75)=45.62, p < 0.001, \eta^2=0.38$). Experimental group demonstrated substantial growth: 17.6 points from $M=61.8 (SD=6.3)$ to $M=79.4 (SD=7.1; within-group d=2.62$). Control group improvement was minimal: 4.9 points from $M=61.2 (SD=6.1)$ to $M=66.1 (SD=6.8; within-group d=0.76$). Between-group difference was substantial ($t(75)=8.67, p < 0.001$, between-group $d=1.91$).

3.3 Secondary Outcomes

3.3.1 Blinded Design Quality Assessment

Independent samples *t*-tests revealed significant between-group differences across all design quality dimensions evaluated by blinded assessors:

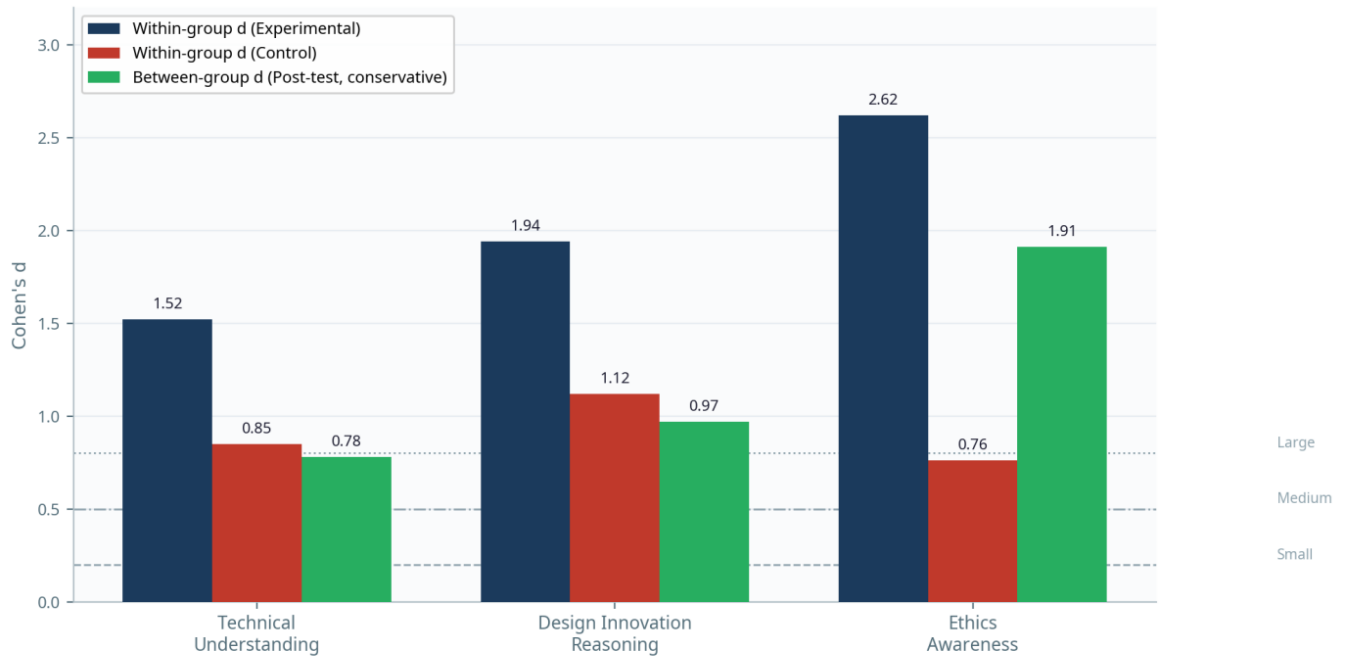


Figure 2. Effect size comparison across three metrics. Between-group d (green) is the most conservative and appropriate metric for RCT evaluation.

Figure 3. Effect size comparison across three metrics. Between-group d (green) is the most conservative and appropriate metric for RCT evaluation.

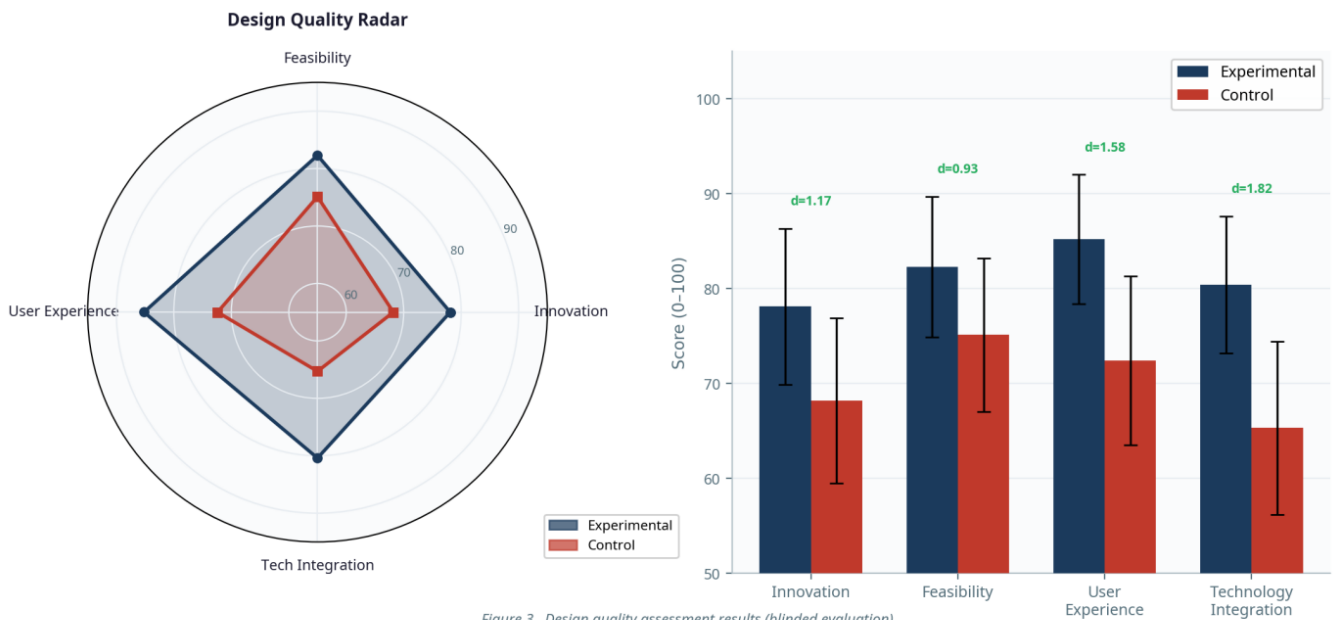


Figure 3. Design quality assessment results (blinded evaluation). Left: radar chart; Right: bar chart with ±1 SD error bars and between-group Cohen's d.

Figure 4. Design quality assessment results (blinded evaluation). Left: radar chart; Right: bar chart with ±1 SD error bars and between-group Cohen's d.

- Innovation: Experimental M=78.1 (SD=8.2) vs. Control M=68.2 (SD=8.7); $t(75)=5.12$, $p < 0.001$, $d=1.17$
- Feasibility: Experimental M=82.3 (SD=7.4) vs. Control M=75.1 (SD=8.1); $t(75)=4.08$, $p < 0.001$, $d=0.93$

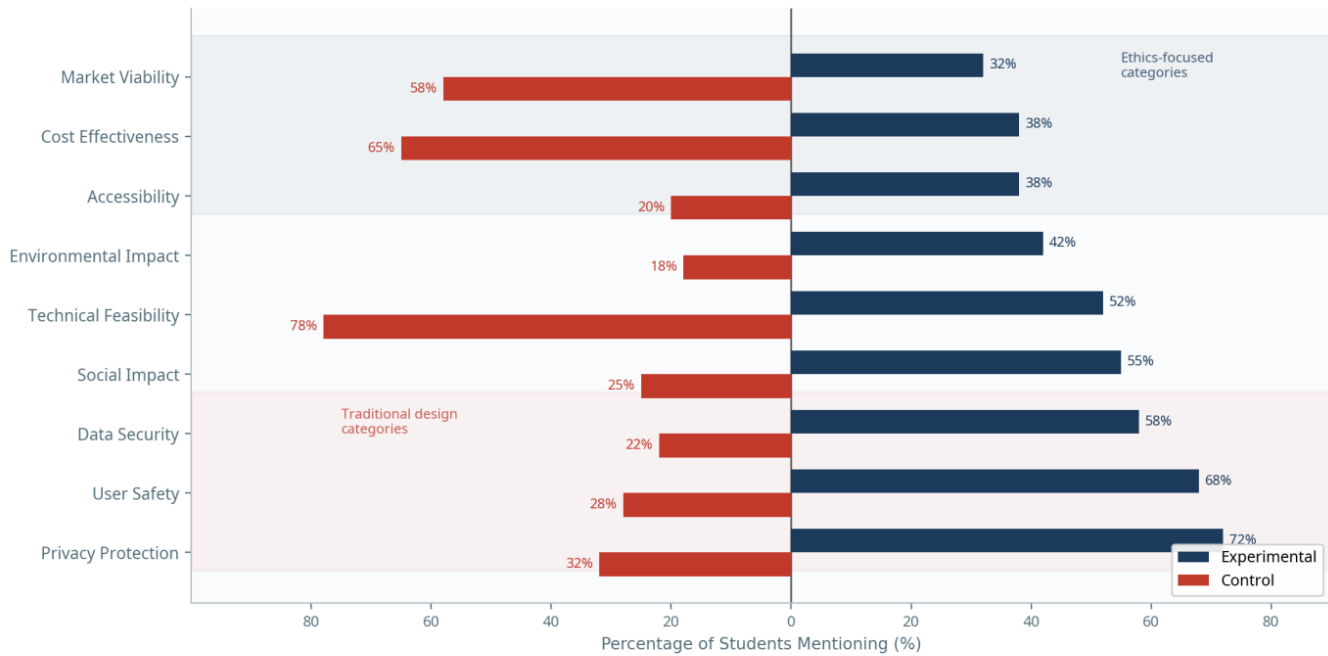


Figure 4. Focus points distribution in student design documentation. Experimental group (right, navy) shows greater emphasis on ethical concerns; Control group (left, red) emphasizes traditional design factors.

Figure 5. Focus points distribution in student design documentation. Experimental group (right, navy) shows greater emphasis on ethical concerns; Control group (left, red) emphasizes traditional design factors.

- User Experience: Experimental M=85.2 (SD=6.8) vs. Control M=72.4 (SD=8.9); $t(75)=6.89, p < 0.001, d=1.58$
- Technology Integration: Experimental M=80.4 (SD=7.2) vs. Control M=65.3 (SD=9.1); $t(75)=7.94, p < 0.001, d=1.82$

3.3.2 Focus Points Analysis

Text mining revealed significant between-group differences in attention patterns ($\chi^2(9)=47.23, p < 0.001$). Experimental group students showed greater focus on Privacy Protection (72% vs. 32%, $p < 0.001$), User Safety (68% vs. 28%, $p < 0.001$), and Data Security (58% vs. 22%, $p < 0.001$). Control group students emphasized traditional concerns more heavily: Technical Feasibility (78% vs. 52%, $p < 0.05$), Cost Effectiveness (65% vs. 38%, $p < 0.05$), and Market Viability (58% vs. 32%, $p < 0.05$).

3.4 Retention and Transfer Effects

Follow-up assessments at 4 weeks post-intervention revealed sustained benefits. Experimental group students maintained 87% of technical understanding improvements, 92% of design innovation reasoning gains, and 89% of ethics awareness increases. Transfer effects were assessed through a novel augmented reality wearables challenge, where experimental group students demonstrated superior performance in problem analysis ($t(75)=3.21, p < 0.01, d=0.74$) and solution quality ($t(75)=2.87, p < 0.01, d=0.66$).

4 Discussion

4.1 Principal Findings and Effect Size Interpretation

This randomized controlled trial provides compelling evidence that interdisciplinary collaborative teaching significantly enhances design innovation reasoning, technical understanding, and ethical awareness among design students. However, the exceptionally large within-group effect sizes (e.g., $d=2.62$ for Ethics Awareness) warrant careful interpretation.

These massive within-group effects are likely inflated by the specific curriculum taught to the experimental group. Because the experimental group received explicit instruction in ethics and engineering-topics not formally covered in the control group’s traditional curriculum—the assessments inherently favored the experimental group’s recent learning experiences. To provide a more robust and conservative estimate of the intervention’s true impact, we emphasize the between-group effect sizes at post-test ($d=0.78$ to 1.91). While still large, these between-group metrics control for baseline differences and provide a more realistic measure of the collaborative model’s superiority over traditional instruction. The substantial between-group effect for ethics awareness ($d=1.91$) challenges assumptions that ethical reasoning develops naturally through design practice and instead suggests that explicit, integrated ethics instruction is essential for cultivating responsible design capabilities [21].

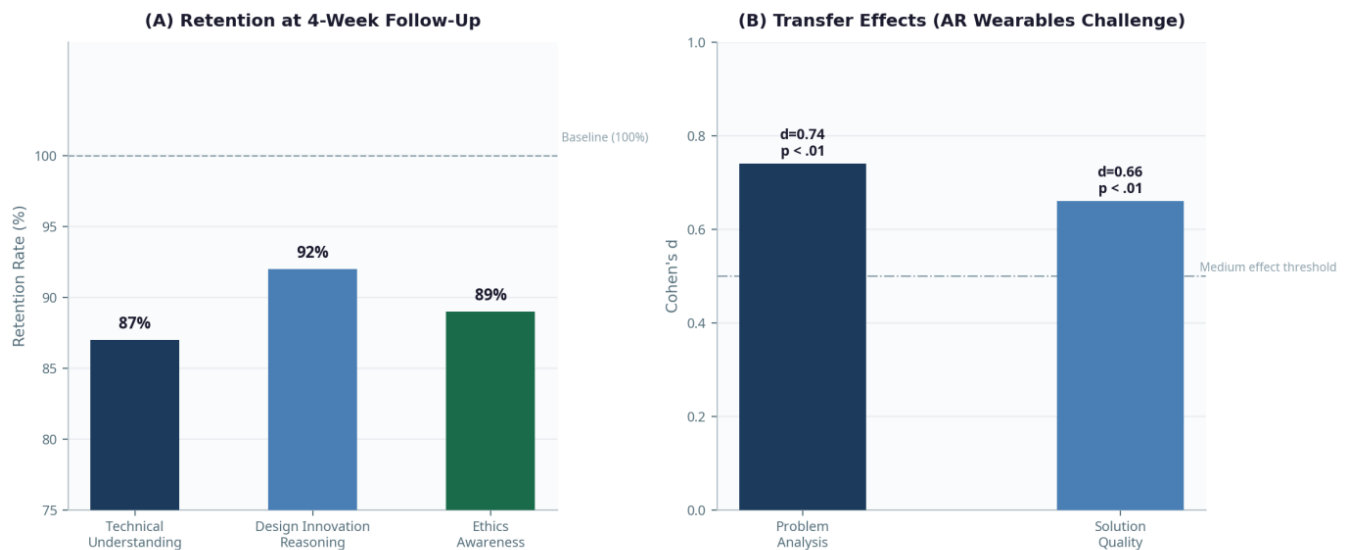


Figure 5. (A) Retention rates of learning gains at 4-week follow-up (experimental group). (B) Transfer effects assessed via a novel AR wearables challenge.

Figure 6. (A) Retention rates of learning gains at 4-week follow-up (experimental group). (B) Transfer effects assessed via a novel AR wearables challenge.

The superior design quality performance, evaluated by strictly blinded assessors, provides strong external validation for the learning assessments and demonstrates that enhanced reasoning capabilities translate into improved practice. The particularly large effect for technology integration ($d=1.82$) suggests that collaborative instruction effectively bridges traditional gaps between design and engineering education [20].

4.2 Mechanisms of Collaborative Learning

The effectiveness of interdisciplinary collaborative teaching likely stems from several complementary mechanisms. First, simultaneous presentation of multiple disciplinary perspectives forces integrative thinking rather than sequential consideration of factors [11]. This mirrors real-world design complexity and develops cognitive flexibility essential for navigating competing constraints [14]. Second, collaborative teaching provides opportunities to observe expert reasoning across disciplines, offering rich models for developing design innovation reasoning capabilities [15]. Third, integration of multiple perspectives promotes boundary-spanning skills increasingly valuable in contemporary practice [2].

4.3 Limitations and Future Directions

Several critical limitations must be considered when interpreting these findings.

First, Resource Disparity and the Hawthorne Effect: The experimental group benefited from a 3:1 instructor model (design, engineering, philosophy) compared to the control group's 1:1 model. This disparity in instructional resources and individualized attention may partially account for the observed improvements, independent of the interdisciplinary curriculum itself. Future studies should attempt to control

for instructional resources, perhaps by utilizing a 3-instructor sequential teaching model in the control group.

Second, Curriculum Domain Confound: The experimental group focused specifically on wearable technology, while the control group focused on general product design. The improvements in technical understanding and ethics awareness may partly reflect domain-specific learning rather than the collaborative teaching model per se.

Third, Long-term Retention: While the 4-week follow-up demonstrated sustained benefits, 4 weeks is a relatively short period for assessing true long-term retention. Future research should employ longer follow-up periods (e.g., 6-12 months) to determine if these interdisciplinary reasoning skills persist into professional practice.

Finally, while we established the structural validity of our measurement instruments through CFA, these tools were newly adapted for this study. Further validation across diverse student populations is necessary.

5 Conclusions

This study demonstrates that interdisciplinary collaborative teaching significantly enhances design innovation reasoning and promotes holistic thinking in wearable technology design education. The integration of design, engineering, and ethics perspectives produces substantial improvements in technical understanding, ethical awareness, and design quality outcomes.

The findings support the adoption of STEAM+D educational frameworks that explicitly integrate design thinking and ethical reasoning with traditional components. Such approaches recognize that responsible technology development

requires technical competence, creative problem-solving, sophisticated ethical reasoning, and systems thinking capabilities. As wearable technologies continue evolving, educational institutions have critical opportunities to prepare designers for the multifaceted challenges of responsible technology development.

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