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An Empirical Study on an Embodied Intelligence–Driven STEAM Curriculum for Enhancing Innovation and Practical Competence in IoT Engineering Undergraduates

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Abstract: *Internet of Things (IoT) engineering requires graduates with strong innovation capabilities, practical skills, and interdisciplinary collaboration abilities. Current curricula suffer from theory-practice disconnection, insufficient interdisciplinary integration, and inadequate project-based learning depth, creating skill gaps in complex engineering problem-solving. This study proposes an integrated teaching model combining embodied intelligence with STEAM education for undergraduate IoT programs. A quasi-experimental design compared experimental and control groups using multiple evaluation dimensions: academic performance, innovation assessments, project outcomes, and teamwork skills, supplemented by qualitative interviews. Results demonstrate that the proposed model significantly enhances students' innovation capabilities, hands-on skills, and cross-disciplinary collaboration. The integration of embodied intelligence with STEAM education effectively addresses existing curriculum limitations and provides a viable pathway for cultivating interdisciplinary talents and advancing higher education curriculum reform.*

Keywords: *Embodied Intelligence; IoT; STEAM; Interdisciplinary Collaboration; Engineering Education*

1. Introduction

The advent of the Fourth Industrial Revolution has accelerated the development of Internet of Things (IoT) technologies, driving transformative changes across global industries, particularly in intelligent manufacturing, smart cities and healthcare. IoT has emerged as a core driver in these domains. According to international projections, the number of IoT devices worldwide is expected to exceed 25 billion by 2030, significantly advancing digital transformation [1]. However, the rapid proliferation of IoT technologies has intensified the demand for engineering professionals equipped with innovative thinking, interdisciplinary collaboration and practical skills. Enhancing the quality and effectiveness of IoT engineering education to cultivate talent capable of meeting future societal needs has thus become a critical issue in global educational reform. Currently, IoT engineering education faces notable challenges in fostering innovation and practical competence, despite numerous curriculum reform efforts. Existing curricula often emphasize theoretical instruction, lacking effective mechanisms for developing students' practical abilities, innovative thinking and interdisciplinary problem-solving skills [2]. Furthermore, innovation in course content and pedagogy has lagged, with many programs remaining confined to traditional, single-discipline frameworks, insufficient to address the comprehensive requirements of rapidly evolving technological fields [3].

The STEAM educational paradigm—integrating science, technology, engineering, arts and mathematics—has been widely adopted in educational reforms. Research has demonstrated that STEAM education, through interdisciplinary collaboration and project-based learning, cultivates students' innovation and practical abilities, particularly in complex problem-solving and teamwork [4,5]. Nevertheless, empirical studies systematically evaluating the integration of STEAM into IoT engineering and its impact on student competence remain limited. In particular, the combination of embodied intelligence theory with STEAM education, and the mechanisms by which embodied intelligence–driven curricula enhance innovation and practical skills in IoT engineering students, have not been sufficiently explored [6].

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Embodied intelligence, as a significant branch of cognitive science, posits that intelligence arises not only from brain processing but also from dynamic interactions between the body and environmen [7]. In educational contexts, embodied intelligence has been shown to facilitate knowledge acquisition and application through situational experience and bodily interaction[8]. For example, studies have indicated that embodied intelligence can effectively foster hands-on skills and creative thinking, especially in complex problem-solving, by supporting cognitive transfer and innovative practic [9]. However, practical research combining embodied intelligence and STEAM education remains scarce, particularly in IoT engineering [10]. Many STEAM implementations still operate within single-discipline knowledge frameworks, lacking deep integration of interdisciplinary, practical and innovative elements. Weak connections between theoretical content and real-world application persist, limiting the development of students' innovation and practical skills. These limitations may hinder students' abilities in interdisciplinary collaboration and complex problem-solving. Therefore, future STEAM education should emphasize the integration of embodied intelligence, leveraging bodily interaction and disciplinary knowledge to holistically enhance student competence. Existing research has primarily focused on the role of embodied intelligence in promoting creative thinking and the impact of STEAM education on interdisciplinary skills. However, studies combining these approaches, especially in emerging fields such as IoT engineering, remain insufficient, with a lack of theoretical and empirical support for improving interdisciplinary collaboration and engineering practice through their integration.

Against this backdrop, the present study seeks to address this gap by investigating the effects and mechanisms of an embodied intelligence–driven STEAM curriculum on the innovation and practical competence of IoT engineering students. By integrating embodied intelligence theory and STEAM educational principles, a novel curriculum was designed and implemented, employing project-based learning and interdisciplinary collaboration. Analysis of data from 500 students (cohorts 2022–2024) provides insights into the curriculum's impact and offers new perspectives and practical pathways for reforming IoT engineering education in China.

2. The Principal Impacts of Embodied Intelligence and STEAM Curriculum on Student Competence

2.1 The Impact of Embodied Intelligence on Student Learning

Embodied intelligence theory posits that learning is not merely a process of information processing in the brain, but is accomplished through bodily engagement with the external world, offering new insights for the field of education. In educational practice, the application of embodied intelligence has gained increasing attention. Research has shown that embodied intelligence can effectively facilitate students' understanding and mastery of complex concepts. For instance, Kosmas et al. introduced situational interaction and bodily participation into science curricula, finding that students achieved a better grasp of abstract knowledge and enhanced cognitive abilities through hands-on experiments and situational simulations [11]. Junus et al. noted that interaction between the body and environment stimulates creative thinking during hands-on practice, conferring significant advantages in problem-solving [12].

Furthermore, Chang et al. demonstrated that embodied intelligence not only promotes students' understanding of disciplinary knowledge but also enhances their creativity, particularly in interdisciplinary problem-solving context [13]. Collectively, these studies provide a new perspective for education, suggesting that bodily participation and environmental interaction can effectively improve learning outcomes and foster innovation. In specific disciplines, the educational application of embodied intelligence exhibits diverse advantages. In science education, teachers design experimental operations and model construction activities, enabling students to experience the process of knowledge generation through practical engagement, thereby deepening their understanding of scientific principles. In engineering education, the introduction of embodied intelligence helps cultivate students' engineering practice and creative thinking. For example, Yan et al. adopted a project-driven approach in mechanical engineering courses, integrating embodied intelligence concepts to significantly enhance students' learning motivation and innovation [14]. In the arts and design, embodied intelligence stimulates creativity and expressiveness through bodily movement and spatial perception. Thus, embodied intelligence theory demonstrates positive effects across educational practices in various disciplines.

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2.2 The Impact of STEAM Curriculum on Students' Comprehensive Competence

The STEAM educational paradigm has been increasingly promoted worldwide, particularly for its significant advantages in fostering interdisciplinary thinking and innovation. STEAM integrates science, technology, engineering, arts and mathematics, advocating project-based, interdisciplinary learning to cultivate students' innovative spirit, problem-solving ability and comprehensive competence [15,16].

In recent years, as the demand for innovative talent has grown, STEAM education has been incorporated into curriculum reforms by educational authorities in many countries. For example, the U.S. Next Generation Science Standards (NGSS) emphasize interdisciplinary integration, while Finland, South Korea and others have actively developed and implemented STEAM curricula at both basic and higher education levels [17]. The core of STEAM curriculum design lies in project-based learning (PBL) and authentic tasks, which stimulate students' interest and initiative. Unlike traditional knowledge-transmission models, STEAM emphasizes the application of multidisciplinary knowledge in solving real problems, fostering innovation, critical thinking and teamwork. Research has shown that STEAM curricula, through project-based learning and practical activities, significantly enhance students' innovation, critical thinking and teamwork [18]. For example, Rosyida et al. found that students in STEAM courses improved their creative thinking and technical application, especially in complex engineering problem-solving [19]. Singh further demonstrated that STEAM education promotes knowledge integration across disciplines, particularly in teamwork and practical activities, significantly improving interdisciplinary collaboration and innovation [20].

In practice, STEAM emphasizes "learning by doing" with hands-on practice, teamwork, and creative design enabling students to experience knowledge generation and application in real or simulated engineering environments. At MIT, for example, the introductory engineering course integrates art and engineering, requiring students to complete the entire process from concept to prototype in teams. This interdisciplinary, project-driven model not only enhances engineering practice but also stimulates innovation. Leading universities in China, such as Tsinghua and Shanghai Jiao Tong, have also explored STEAM in engineering by establishing interdisciplinary innovation classes, achieving positive outcome [21].The benefits of STEAM for students' comprehensive competence are multifaceted. First, innovation is central to STEAM, with open-ended projects requiring students to propose unique solutions, greatly exercising creative and problem-solving skills. Second, STEAM emphasizes teamwork and communication. During projects, students collaborate with peers from different backgrounds, dividing tasks and working together, which enhances teamwork, social and organizational skills. Third, STEAM fosters critical thinking and self-reflection, as students must continually evaluate and optimize their solutions, learning to analyze and solve problems from multiple perspectives [22,23].

2.3 The Potential Impact of Integrating Embodied Intelligence and STEAM Curriculum

Although embodied intelligence and STEAM education have each achieved progress in their respective fields, research combining the two remains limited. Theoretically, integrating embodied intelligence with STEAM can maximize their advantages, especially in enhancing students' innovation and problem-solving abilities [24]. Embodied intelligence, through interaction and practice, enables students to engage bodily with the environment during hands-on activities, stimulating creative thinking and teamwork [25]. This integration provides a more holistic learning experience, fostering innovation and practical competence in real-world problem-solving. Current research on this integration is mainly focused on basic education and preliminary interdisciplinary curriculum design, particularly in primary and secondary education, while studies in higher and professional education (such as IoT engineering) remain scarce. For example, Almarcha et al. explored the introduction of embodied intelligence–driven STEAM curricula in basic education, finding that embodied intelligence significantly enhanced students' creativity and critical thinking in problem-solving [26]. However, most of these studies are limited to basic education, with few addressing the integration in higher education, especially in engineering [27].

In IoT engineering education, how to combine embodied intelligence and STEAM to enhance interdisciplinary thinking and engineering practice remains underexplored. IoT is highly interdisciplinary, requiring students to possess broad technical backgrounds, innovative thinking and teamwork. Effective integration of embodied intelligence and STEAM is thus key to improving students' comprehensive abilities. Through this integration, students can not only solve real engineering problems but also enhance creativity, critical thinking and hands-on skills. Some progress has been made in single-discipline engineering where embodied intelligence and STEAM significantly improved innovation and teamwork [28] However, most research focuses on traditional fields, and as a discipline highly dependent on

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interdisciplinary collaboration, IoT engineering still lacks systematic application and widespread adoption of this integration. IoT curricula are inherently interdisciplinary, involving computer science, electronics and communications, so how to combine embodied intelligence and STEAM to foster innovation and practical competence remains an urgent issue.

3. Data and Methods

3.1 Research Design

A quasi-experimental design was adopted in this study to systematically evaluate the impact of an embodied intelligence–driven STEAM curriculum on the innovation and practical competence of undergraduate students majoring in IoT engineering. The core of the quasi-experimental design lies in conducting interventions in authentic educational settings and revealing the actual effects of educational reform by comparing the learning outcomes of the experimental and control groups. The process consisted of three stages: pretest, intervention and posttest. Initially, all participating students underwent a pretest to ensure no significant differences between the experimental and control groups in key variables such as innovation competence and academic performance. Subsequently, the experimental group received the embodied intelligence–driven STEAM curriculum intervention, while the control group continued with traditional teaching methods. After the course, both groups were post-tested to compare changes in innovation and practical competence. The study sample comprised undergraduates majoring in IoT engineering at a Chinese university, specifically including 100 students from the 2022 to 2024 cohorts. Stratified random sampling was strictly followed to ensure the representativeness and breadth of the sample. Grouping considered the balanced distribution of variables such as gender, grade and academic background, ensuring no significant differences between the experimental and control groups in these aspects. All participants voluntarily participated and signed informed consent forms in accordance with ethical requirements. To ensure representativeness, the sample covered different grades, genders and academic levels, and statistical tests confirmed no significant differences before and after grouping.

3.2 Intervention and Curriculum Implementation

The experimental group participated in a semester-long embodied intelligence–driven STEAM curriculum, which included interdisciplinary projects, bodily interaction experiments and team-based tasks. The curriculum was designed by integrating embodied intelligence theory and STEAM educational principles, covering IoT technology, science, art and engineering, with a focus on interdisciplinary integration and practical skills. The curriculum aimed not only to impart theoretical knowledge but also to stimulate students' innovative thinking and practical competence. The control group received traditional teaching, combining lectures and laboratory work, without the introduction of embodied intelligence or STEAM projects. To standardize the intervention, all courses were designed and delivered by the same teaching team, with consistent syllabi, resources and assessment standards, differing only in teaching methods and activity design.

The STEAM curriculum developed for this study closely integrated embodied intelligence theory with the disciplinary characteristics of IoT engineering, emphasizing interdisciplinary knowledge integration and practical competence. The curriculum covered IoT fundamentals, sensors and embedded systems, data acquisition and analysis, engineering design and artistic expression, striving to establish a close link between theoretical learning and practical application. The course spanned one semester (16 weeks), with weekly sessions including lectures, project seminars and hands-on activities. The overall teaching model combined "theoretical instruction + project-driven learning + teamwork + reflective summary." Each unit was problem-oriented, with interdisciplinary projects designed around typical IoT engineering scenarios. The main components included: Theoretical introduction: Teachers explained IoT fundamentals, embodied intelligence theory and STEAM principles to help students build an interdisciplinary knowledge framework. Project initiation: Each project cycle lasted 2–3 weeks, with teachers announcing project topics and students forming teams of 4–6 based on interests and strengths, with clear roles (e.g., hardware design, software development, data analysis, art design, project management). Solution design and implementation: Team members collaboratively developed project plans, divided tasks, and used class and extracurricular time for research, proposal validation, prototyping and implementation. Teachers and teaching assistants held regular seminars to provide technical guidance and formative feedback. Classroom activities and embodied experience: Through simulations, role-playing and experimental operations, students' understanding and application of knowledge were reinforced. For example, students built sensor networks and conducted data collection and environmental interaction experiments to enhance hands-on skills and innovative thinking. Outcome presentation and evaluation: At the end of each project cycle, teams presented their results, including project reports, demonstrations and artistic expression. Teachers, peers and external experts jointly evaluated outcomes, focusing on innovation, practicality, teamwork and artistic performance. Reflection and summary: After each project, students submitted individual reflection reports, and teachers organized group discussions to promote experience sharing and competence improvement.

The following are two project cases from the study: 1) Smart Classroom Environmental Monitoring System Design: Students were tasked with designing and implementing an IoT-based classroom environmental monitoring system capable of real-time data collection (temperature, humidity, CO_2 concentration) and visualization with alerts. Team roles were clearly defined: two students handled sensor hardware selection and circuit design, one developed embedded programming and data acquisition, one designed the visualization interface, and another managed the project and artistic expression (e.g., interface aesthetics, user experience). During implementation, the team encountered challenges such as unstable sensor data and wireless communication delays. By consulting literature, seeking instructor guidance and repeated experimentation, the team optimized data acquisition algorithms and adopted multithreading to improve system responsiveness. In interface design, the art member integrated data visualization with classroom layout to enhance user experience. The system was successfully deployed and well received during the presentation, demonstrating improvements in engineering practice, innovation, teamwork and interdisciplinary integration. 2) Smart Campus Interactive Art Installation: This project required teams to design an interactive installation combining IoT technology and artistic creativity to enhance campus aesthetics and interactivity. Team members came from electronics, computer science and art backgrounds. Through brainstorming, the team proposed a "luminous smart walkway" using pressure sensors and LED strips, where lighting effects changed with footsteps and speed. Challenges included sensor sensitivity, lighting control algorithms, and balancing artistic and technical requirements. Art and engineering members collaborated closely, repeatedly adjusting structure and lighting for feasibility and aesthetics. The project manager coordinated progress, resources and communication. The installation was successfully exhibited on campus open day, attracting wide participation and acclaim, fully reflecting the goals of interdisciplinary integration, embodied experience and innovative practice in the STEAM curriculum.

3.3 Data Collection

Data collection included both quantitative and qualitative data to comprehensively assess the impact of curriculum reform on students' overall competence. Quantitative data included academic performance, project outcomes, innovation competence assessments and interdisciplinary project participation. These metrics quantified students' performance in innovation, practical skills and interdisciplinary collaboration. Innovation competence was measured using a self-developed questionnaire covering creativity, problem-solving and knowledge transfer, reviewed by experts (Cronbach's $\alpha = 0.87$, indicating high reliability). Project outcome scoring standards referenced domestic and international STEAM evaluation systems and were tailored to the actual projects. Qualitative data were collected through surveys, in-depth interviews and classroom observations to gain insights into student feedback, changes in learning attitudes, innovation and teamwork. Specific methods included: 1) Surveys: Likert-scale questionnaires assessed student feedback, course experience and interest, with ratings for interactivity, innovation, hands-on practice, etc. 2) In-depth interviews: Representative students from both groups participated in semi-structured interviews on course experience, changes in innovation and teamwork. 3) Classroom observation: Standardized scales recorded classroom interaction, teamwork and innovation for qualitative analysis.

3.4 Data Analysis Methods

Data analysis was conducted using SPSS 26.0 and other statistical software. Descriptive statistics were first used to analyze means, standard deviations and other characteristics. Independent-samples t-tests and ANOVA were then used to compare significant differences between groups in innovation, practical skills, etc. Multiple regression analysis explored the effects of learning attitude, project engagement and interdisciplinary collaboration on competence improvement. Qualitative data were analyzed using content analysis, with two researchers independently coding interview and observation records, extracting key themes by thematic analysis, and achieving a Kappa coefficient of 0.82 to ensure objectivity and reliability.

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4. Results and discussion

4.1 Quantitative Data Analysis

This study assessed the effects of the embodied intelligence–driven STEAM curriculum on the innovation and practical competence of 500 IoT engineering undergraduates by measuring academic performance, innovation tests, project outcomes and interdisciplinary collaboration. To ensure data validity and reliability, descriptive statistics, t-tests, ANOVA, and regression analyses were employed for both the experimental and control groups across all dimensions.

4.1.1 Academic Performance

Academic performance serves as a key indicator of students' mastery of theoretical knowledge. In this study, quantitative analysis was conducted on the academic performance of both groups to verify the impact of the embodied intelligence–driven STEAM curriculum. As shown in Table 1, The experimental group achieved an average academic score of 85.6 (SD = 6.23), while the control group averaged 78.2 (SD = 7.12). Results from the independent-samples t-test indicated a significant difference between the groups ($t = 4.67$, $p < 0.01$), demonstrating that the embodied intelligence–driven STEAM curriculum effectively improved academic achievement. The standard deviation, an important measure of data dispersion, was notably lower in the experimental group (6.23) than in the control group (7.12), indicating more concentrated performance among experimental group students. A smaller standard deviation suggests less fluctuation and that most students' scores are close to the mean. In contrast, the control group's larger standard deviation reflects greater variability. These findings not only highlight the academic advantage of the experimental group but also reveal that the embodied intelligence–driven STEAM curriculum enhances the consistency and stability of academic performance. This is consistent with the findings of Shen, who reported that innovation-driven teaching models reduce individual differences and improve overall academic achievement [29].

Table 1: Comparison of Academic Performance between Experimental and Control Groups.

Group	Mean Score	SD	t	p
Experimental	85.6	6.23	4.67	<0.01
Control	78.2	7.12		

As shown in Table 2, Further regression analysis showed significant positive correlations between academic performance and learning attitude ($\beta = 0.35$, $p < 0.01$, *$p < 0.05$), as well as project engagement ($\beta = 0.42$, $p < 0.01$). In addition, interdisciplinary collaboration had a positive effect on academic performance (coefficient = 0.21, $p < 0.05$), indicating that students' performance in interdisciplinary collaboration positively influenced their academic achievement. Specifically, interdisciplinary collaboration not only enhanced students' comprehensive abilities in practical projects but also promoted deeper understanding and application of course content.

Table 2: Multiple Regression Analysis Results (Academic Performance).

Variable	Regression Coefficient (β)
Learning Attitude	0.35**
Project Engagement	0.42**
Interdisciplinary Collaboration	0.21*

4.1.2 Innovation Competence Test

Analysis of academic performance indicated that the embodied intelligence–driven STEAM curriculum improved students' mastery of theoretical knowledge. To further explore its effect on higher-order abilities, students' innovation competence was analyzed. As shown in Table 3, Innovation competence, reflecting problem-solving, idea generation and creative thinking, was statistically analyzed for both groups. The experimental group's mean innovation score was 75.3 (SD = 5.15), while the control group's was 68.4 (SD = 6.98). The independent-samples t-test revealed a statistically significant difference ($t = 5.32$, $p < 0.01$), indicating that the curriculum effectively enhanced innovation competence. The experimental group's standard deviation (5.15) was significantly lower than that of the control group (6.98), suggesting more consistent performance. In other words, most experimental group students'scores were close to the mean, indicating the curriculum not only improved innovation competence but also reduced individual differences. In contrast, the control group's larger standard deviation indicated greater variability, suggesting that traditional teaching was less effective in improving innovation competence for all students. These results demonstrate that the embodied intelligence–driven STEAM curriculum significantly enhanced students' creative thinking, particularly in applying disciplinary knowledge to

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new contexts.

Table 3: Comparison of Innovation Competence Scores between Experimental and Control Groups.

Group	Mean Score	SD	t	p
Experimental	75.3	5.15	5.32	<0.01
Control	68.4	6.98		

As shown in Table 4, path analysis was conducted to identify key factors influencing the improvement in innovation competence. The results showed that learning attitude and interdisciplinary collaboration had significant positive path effects on innovation competence (learning attitude path coefficient = 0.40, $p < 0.01$; interdisciplinary collaboration path coefficient = 0.35, $p < 0.01$), indicating that the curriculum promoted innovation competence by stimulating learning motivation and enhancing interdisciplinary collaboration.

Table 4: Path Analysis Results (Innovation Competence).

Variable	Path Coefficient (β)	p
Learning Attitude	0.40**	<0.01
Interdisciplinary Collaboration	0.35**	<0.01

4.1.3 Project Outcomes and Practical Competence

As shown in Table 5, the study further evaluated project outcomes and practical competence in both groups. The experimental group's mean project score was 92.4 (SD = 4.62), while the control group's was 84.1 (SD = 5.43). ANOVA results indicated a significant difference ($F = 8.45$, $p < 0.01$), demonstrating that the curriculum significantly improved practical competence and project outcomes. The experimental group's standard deviation (4.62) was lower than that of the control group (5.43), indicating more consistent performance. Most experimental group students' scores were close to the mean, reflecting high consistency. In contrast, the control group's larger standard deviation indicated greater variability, suggesting that traditional teaching was less effective in improving practical competence for all students.

Table 5: Comparison of Project Scores between Experimental and Control Groups.

Group	Mean Score	SD	F	p
Experimental	92.4	4.62	8.45	<0.01
Control	84.1	5.43		

As shown in Table 6, further regression analysis revealed significant positive relationships between project scores and project engagement ($\beta = 0.42$, $p < 0.01$) and learning attitude ($\beta = 0.28$, $p < 0.01$). Project engagement had the greatest impact, indicating that students who actively participated in projects achieved higher practical competence and project outcomes.

Table 6: Multiple Regression Analysis Results (Practical Competence).

Variable	Regression Coefficient (β)
Project Engagement	0.42**
Learning Attitude	0.28**

4.1.4 Interdisciplinary Collaboration and Teamwork

As shown in Table 7, the improvement of practical competence is closely linked to teamwork and interdisciplinary collaboration. To comprehensively evaluate the curriculum's effects, students' teamwork and interdisciplinary collaboration were analyzed. The experimental group's mean teamwork score was 89.2 (SD = 5.17), while the control group's was 80.3 (SD = 6.02). The independent-samples t-test revealed a significant difference ($t = 6.21$, $p < 0.01$), indicating that the curriculum significantly improved interdisciplinary collaboration. The experimental group's standard deviation (5.17) was lower than that of the control group (6.02), indicating more consistent performance. Most experimental group students' scores were close to the mean, while the control group's larger standard deviation indicated greater variability. These results further demonstrate that the curriculum not only improved interdisciplinary collaboration but also enhanced consistency and teamwork. The difference in standard deviation suggests that the curriculum helped experimental group students perform more stably in team projects, reducing individual differences.

Table 7: Comparison of Teamwork Scores between Experimental and Control Groups.

Group	Mean Score	SD	t	p
Experimental	89.2	5.17	6.21	<0.01
Control	80.3	6.02		

4.1.5 Comprehensive Competence Differences between Groups

A comparative analysis was conducted on the overall performance of the experimental and control groups in terms of innovation ability, practical ability and teamwork skills. The results indicate that the embodied intelligence–driven STEAM curriculum exerts a significant positive impact on students' comprehensive competence, with particularly pronounced effects in fostering creative thinking and hands-on problem-solving skills. Statistical analysis revealed that the mean scores of the experimental group in both innovation and practical ability dimensions were significantly higher than those of the control group ($t = 5.32$, $p < 0.01$), demonstrating the curriculum's effectiveness in stimulating creative thinking and enhancing the ability to address real-world problems.

The project-based learning approach not only promoted improvements in academic performance but also strengthened students' capacity for practical application and problem-solving in authentic contexts. In terms of teamwork skills, students in the experimental group also outperformed their counterparts in interdisciplinary collaboration and project-based cooperation. Specifically, their average scores in team coordination and cross-disciplinary task execution were significantly higher than those of the control group, reflecting the curriculum's effectiveness in cultivating interdisciplinary collaboration and teamwork spirit.

Experimental group students demonstrated a strong sense of cooperation in interdisciplinary projects and effectively integrated knowledge and skills from multiple disciplines to collaboratively address complex engineering challenges. In the visualization analysis (Figure 1), to ensure clarity and align with the teamwork-oriented nature of the curriculum, scatter plots were generated at the project-team level. Each project team consisted of 4–6 students, whose performance in academic achievement, innovation ability, and teamwork skills was aggregated to form a team-level score. Each point in the plot represents the average score of one project team, with 50 project teams in both the experimental and control groups. For statistical inference and significance testing, the full individual-level dataset ($n = 500$) was used, and cluster-robust standard errors were applied to account for intra-group correlation. The visualization clearly illustrates the score differences across dimensions between the two groups, with the experimental group exhibiting particularly strong interactive performance between academic achievement and innovation ability, further supporting the effectiveness of integrating embodied intelligence with STEAM education in enhancing students' comprehensive competence.

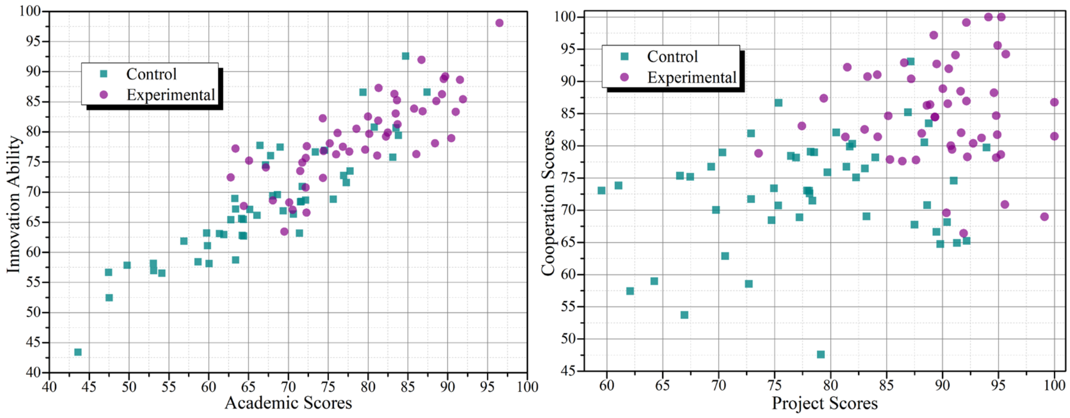

Figure 1: Scatter plot of students' innovation ability and academic performance.

Overall, the embodied intelligence–driven STEAM curriculum significantly improved students' comprehensive competence by integrating innovation, practical skills and interdisciplinary collaboration. The outstanding performance of the experimental group in these dimensions provides strong support for the study's findings and valuable experience and data for future educational practice.

4.2 Qualitative Data Analysis

Qualitative data were collected through surveys, in-depth interviews and classroom observations to

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gain deeper insights into student feedback, changes in learning attitudes, innovation and teamwork. Analysis revealed the following changes among experimental group students: 1) Enhancement of creative thinking: Most experimental group students reported that the curriculum encouraged more active problem-solving and enabled them to address complex issues through hands-on activities. Interview records indicated that students learned to integrate interdisciplinary knowledge to propose innovative solutions. 2) Changes in learning attitude: Experimental group students generally showed higher interest and engagement. Survey results showed an average interest score of 4.2 for the experimental group, compared to 3.5 for the control group ($p < 0.01$), indicating that the curriculum effectively stimulated learning interest and promoted active participation. 3) Teamwork experience: In terms of interdisciplinary collaboration, experimental group students reported that the project-driven approach improved their teamwork. Interview records indicated that students not only deepened their understanding of different disciplines but also enhanced communication and collaboration skills.

4.3 Comprehensive Analysis

Through comprehensive analysis of quantitative and qualitative data, this study confirmed the significant enhancement of innovation, practical competence and interdisciplinary collaboration by the embodied intelligence–driven STEAM curriculum. The experimental group outperformed the control group in all test dimensions, particularly in creative thinking, practical operation and teamwork, demonstrating higher levels of comprehensive competence. These results confirm that the integration of embodied intelligence and STEAM effectively promotes the development of students' innovation competence. The experimental group's significantly higher innovation scores indicate that embodied intelligence, by strengthening interaction with the physical environment, stimulated creative thinking. Embodied intelligence theory posits that cognition depends not only on brain processing but also on bodily-environmental interaction [30]. This was validated in the present study: experimental group students, through hands-on activities and bodily participation, more effectively transformed abstract knowledge into practical application, thereby enhancing their problem-solving abilities. Regression analysis further revealed the positive effects of learning attitude and project engagement on innovation competence, supporting the mechanism by which embodied intelligence stimulates learning motivation to foster innovation.

The results also confirm the curriculum's outstanding performance in enhancing practical competence. Students' excellent performance in project outcomes and practical activities, especially in solving real engineering problems, demonstrates the significant effect of project-based learning on practical competence. The core of STEAM education lies in integrating knowledge and skills from multiple disciplines, emphasizing problem-solving processes rather than mere theoretical instruction. Through interdisciplinary projects, students not only improved hands-on skills but also developed comprehensive interdisciplinary thinking, demonstrating stronger operational and problem-solving abilities in practice.

5. Conclusion

This study focused on the application and effects of an embodied intelligence–driven STEAM curriculum in IoT engineering education, employing a quasi-experimental design and combining quantitative and qualitative analyses to systematically evaluate its impact on students' innovation competence, practical competence and interdisciplinary collaboration. The results demonstrated that the curriculum significantly enhanced students' core competencies in these three areas, with project engagement and learning attitude exerting significant positive effects. Qualitative analysis revealed the underlying mechanisms of competence improvement, namely, the reinforcement of bodily-environmental interaction and the construction of interdisciplinary collaboration contexts, which promoted cross-domain knowledge integration and improved team efficiency. Theoretically, this study organically integrated embodied intelligence theory with STEAM educational principles, expanding the research perspective of STEAM education in higher engineering education and providing new empirical evidence for understanding the mechanisms underlying the formation of interdisciplinary competence. The findings further confirmed the role of embodied intelligence in promoting cognitive development and skill transfer in complex engineering education contexts. Practically, the curriculum model offers a feasible pathway for talent cultivation in IoT and related engineering disciplines. The interdisciplinary integration and project-driven features of the curriculum align with the requirements of emerging engineering education and provide valuable references for curriculum optimization, teacher training and interdepartmental collaboration. It should be noted that the experimental period of this study was one semester, the sample was limited to a single institution, and long-term effects were not tracked. These

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limitations suggest that future research should employ larger samples, more diverse backgrounds and longitudinal tracking to further validate and optimize the curriculum model. Additionally, future studies could utilize learning analytics to explore the moderating effects of individual differences, enabling more precise educational interventions.

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