

# 在光電工程概論導入 STEAM 教學以提升學生學習成效之探討

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## 摘要

本研究旨在探討於大學一年級「光電工程概論」課程中導入STEAM（科學、技術、工程、藝術、數學）教學法，對學生學習成效、專業知識、實務技能及整合創新能力之影響。針對傳統工程基礎課程常面臨理論抽象、學生學習動機低落及實務連結不足等困境，本研究採準實驗研究設計，以南臺科技大學半導體與光電工程系一年級共 132 名修課學生為研究對象。將學生分為實驗組（70人）與對照組（62人），對照組採傳統講述與基礎實習教學，實驗組則導入為期八週之STEAM教學法。實驗組學生以 3 至 6 人為一組，分別進行「太陽光電」、「光通訊」及「LED照明」等三大主題之STEAM實體作品製作與發表。研究工具包含基本知識測驗以及採 Likert 5 點計分之學習成效滿意度量表，並輔以開放性質性回饋進行三角檢視。研究結果顯示，實驗組在整體學習成效滿意度平均得分達 4.51 分，顯著優於對照組之 4.369 分（ $p < .05$ ）。在具體能力認同度上，實驗組於「培育專業知識」達 90.74%（對照組84.62%）、「實務技能培訓」達 50.00%（對照組26.92%），於「整合創新培育」更達 31.48%，大幅高於對照組之 11.54%。質性回饋進一步證實，STEAM中的「藝術（Arts）」元素與動手實作，能有效激發學生的學習心流與團隊溝通能力。研究結論指出，STEAM教學法不僅能鞏固光電工程基礎知識，更能顯著弭平學用落差，大幅提升大一學生之實務動手做能力與跨領域整合創新思維。

**關鍵詞：**光電工程概論、STEAM 教學、學習成效、整合創新、工程教育

## Exploring the Enhancement of Student Learning Outcomes through the Integration of STEAM Education in an Introduction to Optic-Electrical Engineering Course

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### Abstract

This study investigates the impact of integrating STEAM (Science, Technology, Engineering, Arts, Mathematics) education into a freshman-level *Introduction to Optic-Electrical Engineering* course on students' learning outcomes, practical skills, and integrative capabilities. Traditional engineering introductory courses often face challenges, including abstract theoretical content, limited student engagement, and insufficient opportunities

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for practical application. To address these issues, a quasi-experimental design was employed with 132 first-year students from the Department of Semiconductor and Opto-electronic Engineering. Participants were divided into an experimental group ( $n = 70$ ) and a control group ( $n = 62$ ). The control group received traditional lectures and basic practical training, while the experimental group participated in an 8-week STEAM-based instructional module. Students in the experimental group worked collaboratively in teams of three to six to design and present physical STEAM projects focused on *Solar Photovoltaics*, *Optical Communication*, and *LED Lighting*. Data were collected using knowledge assessments, a five-point Likert scale learning satisfaction questionnaire, and open-ended qualitative feedback. The results indicated that the experimental group achieved a significantly higher mean satisfaction score ( $M = 4.51$  vs.  $M = 4.37$ ,  $p < .05$ ) and reported greater competency recognition across three domains: Professional Knowledge (90.74% vs. 84.62%), Practical Skills Training (50.00% vs. 26.92%), and Integration and Innovation (31.48% vs. 11.54%). Qualitative findings further revealed that the hands-on project format and the Arts component of STEAM effectively stimulated students' flow experience and collaborative communication. These results suggest that STEAM integration not only consolidates foundational theoretical knowledge but also substantially bridges the theory–practice gap, enhancing freshman engineers' practical abilities and cross-disciplinary innovative thinking.

**Keywords:** Introduction to Optic-Electrical Engineering, STEAM education, Learning outcomes, Integration and innovation, Engineering education

## I. Introduction

### 1. Research Background and Motivation

Optic-electrical engineering is a core cornerstone of modern high-tech industries, encompassing critical fields such as semiconductor manufacturing, green energy technologies, advanced displays, laser applications, and optical communications. As Taiwan plays an irreplaceable role in the global semiconductor and optoelectronics supply chain, the industry's demand for high-level engineering talents with cross-disciplinary integration capabilities is growing exponentially to enhance overall employment competitiveness [1]. However, the teaching of the first professional compulsory course, "Introduction to Optic-Electrical Engineering," in both vocational systems and general university engineering education often faces severe challenges.

Traditional foundational engineering courses predominantly rely on lecture-based learning, focusing on deductive formula derivations and optical theories (e.g., Maxwell's equations, wave optics, geometric optics). Under this pedagogical model, students easily experience learning frustration when lacking connections to practical contexts. Engineering education research indicates that tedious theoretical derivations tend to cause an overload of "Extraneous Cognitive Load," which subsequently affects students' retention rates and professional identity [2]. According to statistics from our university's Institutional Research Office, the dropout and suspension rate among freshmen has shown a slight upward trend over the years. Furthermore, students in the Department of Semiconductor and Opto-electronic Engineering come from diverse admission channels (including high school applications, vocational electrical clusters, mechanical clusters, and even non-related disciplines). The significant disparity in students' entry behaviors and foundational mathematical abilities makes it difficult for a single, passive lecture-based teaching method to meet the needs of diverse learners.

Moreover, reviewing the learning feedback from engineering students and the industry's evaluation reports on fresh graduates reveals that while students believe most courses are helpful in "cultivating professional knowledge," their training in practical "hands-on skills" and "cross-disciplinary integration and innovation" remains relatively weak. This phenomenon highlights the prevailing "theory-practice gap" dilemma in current

higher engineering education: students may possess good unilateral problem-solving skills on paper but lack the cross-disciplinary integration ability to transform textbook theories into actual engineering products or to face real-world problems with no standard answers.

## 2. Research Purpose

To address the difficulties in traditional optic-electrical engineering education and respond to the current industry's thirst for innovative practical talents, this study proposes integrating the STEAM (Science, Technology, Engineering, Arts, Mathematics) innovative teaching method into the freshman "Introduction to Optic-Electrical Engineering" course. Through collaborative grouping and Project-Based Learning (PBL), students are guided to develop and present physical optic-electrical projects (such as solar photovoltaics, optical communication, and LED lighting). The specific objectives of this study are as follows: (1) To investigate the impact of implementing the STEAM teaching method on the overall learning outcomes and satisfaction of freshmen in the "Introduction to Optic-Electrical Engineering" course. (2) To quantitatively compare the differences in effectiveness between STEAM teaching (experimental group) and traditional teaching (control group) across three core competencies: "Cultivating Professional Knowledge," "Practical Skills Training," and "Integration and Innovation Training." (3) To deeply analyze the psychological learning processes and behavioral changes of freshmen during their participation in STEAM optic-electrical projects through qualitative feedback.

## II. Literature Review

### 1. Challenges in Optic-Electrical Engineering Education and Cognitive Load

Optic-electrical engineering is a highly interdisciplinary subject involving complex knowledge from physical optics, electronic circuits, materials science, and quantum mechanics. Abstract concepts such as electromagnetic wave transmission, diffraction, interference, and energy level transitions pose an extremely high learning threshold for freshmen who have just entered the university. Previous literature points out that the traditional teacher-centered, theory-oriented teaching model often results in students "knowing the 'how' but not the 'why'." Students expend most of their energy memorizing formulas by rote but lack the ability to correspond mathematical formulas to actual engineering designs [3].

From the perspective of "Cognitive Load Theory" in cognitive psychology, when the learning content itself has high interconnectivity and complexity (high intrinsic cognitive load), if the teacher also adopts a one-way lecture method lacking visualization and physical assistance (causing high extraneous cognitive load), the students' working memory capacity will instantly overload, leading to learning stagnation or even abandonment [4]. Therefore, scholars advocate that if introductory engineering courses can break the framework of blackboard lectures, introduce authentic engineering contexts, and encourage hands-on practice—transforming abstract physical phenomena into visible and tangible physical projects—it will be a key strategy to reduce cognitive load and enhance learning outcomes [5].

### 2. Application of STEAM Education and Constructivism in Engineering Education

The STEM education philosophy, initially proposed by the National Science Foundation, emphasizes the interdisciplinary integration of Science, Technology, Engineering, and Mathematics. Subsequently, educational scholar Yakman [6] further developed the STEAM education framework, boldly incorporating the "Arts" element. The "Arts" here refers not only to fine arts and painting in a narrow sense but also broadly covers design thinking, humanistic literacy, aesthetic presentation, and team communication and expression skills. In modern high-tech research and development, a successful product requires not only precise parameter calculations (M) and circuit

design (E) but also consideration of the human-computer interaction of the user interface, the industrial design of the product's appearance, and the narrative ability to present the results to investors or clients (A).

The underlying logic of the STEAM teaching method is deeply influenced by "Constructivism." Constructivism emphasizes that knowledge is not unilaterally transmitted from teacher to student, but rather actively "constructed" by learners through interaction with authentic contexts and the process of solving problems. Through STEAM Project-Based Learning, students face real engineering problems without a single standard answer. They must communicate and coordinate within a team, search for cross-disciplinary resources, experience "trial and error," and personally assemble the projects.

Recent empirical studies have confirmed that integrating hands-on projects into first-year university engineering courses does not weaken students' theoretical foundation by dividing class time. Instead, it enhances students' deep understanding and long-term memory of theoretical knowledge through the intrinsic motivation of "actively seeking answers to complete the project." Simultaneously, such courses can significantly strengthen students' system integration thinking, peer collaboration skills, and resilience when facing unknown problems [3, 7].

### III. Methodology

#### 1. Research Design and Participants

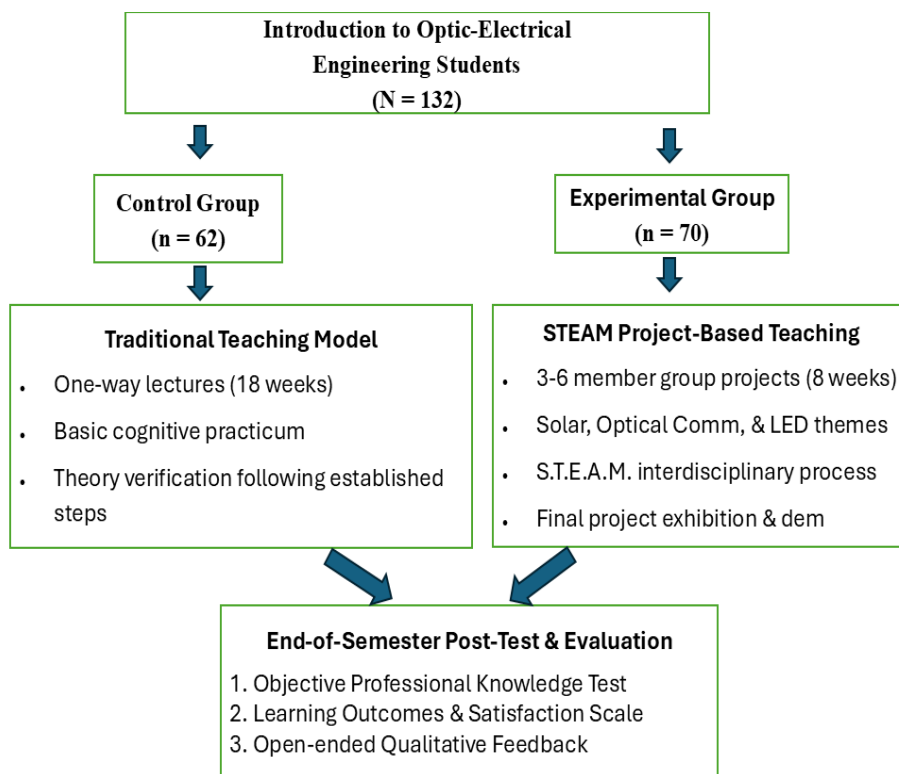
To ensure the validity of the experimental results, a homogeneity test was conducted before the pedagogical intervention. The participants included 132 freshmen from the Department of Semiconductor and Opto-electronic Engineering. As shown in Table 1, there were no statistically significant differences between the experimental group (n=70) and the control group (n=62) in terms of prior knowledge scores ( $t = 0.482$ ,  $p = 0.631$ ), gender distribution ( $\chi^2 = 0.075$ ,  $p = 0.784$ ), and admission background ( $\chi^2 = 0.040$ ,  $p = 0.841$ ). These results confirm that the two groups possessed a high degree of initial homogeneity, providing a solid scientific foundation for the subsequent comparative analysis.

**Table 1.** Homogeneity Test of Participants in Experimental and Control Groups

Variable	Experimental Group (n=70)	Control Group (n=62)	Statistical Value	p- value
Pre-test Score (Mean/SD)	72.54 (8.12)	71.85 (8.43)	$t = 0.482$	0.631
Gender (Male %)	88.6% (n=62)	87.1% (n=54)	$\chi^2 = 0.075$	0.784
Admission Source (Vocational %)	75.7% (n=53)	74.2% (n=46)	$\chi^2 = 0.040$	0.841

#### 2. Teaching Procedure and Course Planning

This course was planned for a total of 18 weeks over one semester. In the early part of the semester, both groups of students received the same foundational opto-electrical theoretical instruction (e.g., basics of geometric optics, introduction to semiconductor materials) to ensure students possessed the most basic disciplinary vocabulary. The core instructional intervention differences between the experimental and control groups occurred in the middle to late stages of the semester, as detailed in the research design framework in Figure 1.



**Figure 1.** Research Design and Flowchart of Integrating STEAM Teaching Method into Introduction to Optic-Electrical Engineering

**(1) Control Group (Traditional Teaching Model)**

Primarily received the traditional "Introduction to Optic-Electrical Engineering" teaching. The instructor predominantly used classroom lectures (PowerPoint presentations), supplemented by basic cognitive practicums with established steps and routines (e.g., following a lab manual to wire circuits and record data). Students passively absorbed knowledge based on textbook theories. The variables in the experimental process were all controlled by the instructor, lacking segments that allowed students to brainstorm, debug, and design practically on their own.

**(2) Experimental Group (STEAM Teaching Model)**

In addition to a streamlined version of theoretical lectures, an 8-week "STEAM Project-Based Teaching for Introduction to Optic-Electrical Engineering" was introduced into the course. The specific 8-week implementation schedule for the experimental group is shown in Table 2.

**Table 2.** The 8-Week STEAM Teaching Schedule for the Experimental Group

Week	STEAM Phase	Description of Teaching Content and Student Activities
Weeks 1-2	Project Initiation and Team Building	Students formed groups of 3-6. The instructor introduced three major project themes: (1) Solar Photovoltaics, (2) Optical Communication, and (3) LED Lighting. Each group selected a theme, conducted a preliminary literature review, and divided tasks.
Weeks 3-4	Foundation in Science (S) and Mathematics (M)	Groups conducted parameter calculations and theoretical verifications for their themes. For example, calculating the required current-limiting resistor size for LED series/parallel circuits; calculating the estimated power generation of a solar panel at different tilt angles.

(continued)

Week	STEAM Phase	Description of Teaching Content and Student Activities
Weeks 5-6	Practice in Technology (T) and Engineering (E)	Entering the physical hands-on phase. Students learned to use soldering irons for circuit board soldering, laser cutters or 3D printers for mechanical prototyping, and assembled optic-electrical components into functional prototypes, while conducting troubleshooting and debugging.
Week 7	Arts (A) and Aesthetic Design	Focused on the appearance and modeling design of the product and optimizing the user interface. Students were also required to plan a visual presentation for the final exhibition and could use VR 360 cameras to record their project features.
Week 8	Cross-Disciplinary Release Conference	Held a final STEAM project exhibition. Each group took the stage for a 10-minute presentation and live demonstration (Demo), and fielded questions and evaluations from instructors, industry mentors, and peers.

As shown in Table 2 and Figure 1, students in the experimental group had to go through a complete process from scratch. For instance, the group choosing the "Optical Communication Project" not only needed to understand the principle of total internal reflection in optical fibers (S), but also calculate the signal attenuation rate (M), then actually manually splice optical fibers and set up the transmitter and receiver circuits (T & E), and finally package the entire system into an educational module with commercial display potential, while articulating their design concepts fluently on stage (A).

### 3. Research Instruments and Data Collection

This study collected data at the end of the semester using structured questionnaires and assessment tools. All questionnaires and test items were reviewed by three experts in the fields of optic-electrical engineering and science education for "Expert Validity" prior to administration, ensuring the items aligned with the research objectives. The assessment tools included:

#### (1) Objective Professional Knowledge Test

Contained multiple-choice questions across three dimensions: "Environmental and Sustainable Development Knowledge," "Electrical Engineering Knowledge" (e.g., series/parallel calculations, basic circuit reading), and "Introduction to Optic-Electrical Engineering Knowledge" (e.g., optical communication principles, solar photoelectric conversion mechanisms), to assess students' theoretical cognitive level in hard skills.

#### (2) Learning Outcomes and Satisfaction Scale

This scale used a 5-point Likert scale (5 = Strongly Agree, 1 = Strongly Disagree). The items covered the practicality of teaching materials and learning engagement, and specifically established three core sub-dimensions to investigate students' self-recognition: "Cultivating Professional Knowledge," "Practical Skills Training," and "Integration and Innovation Training." Upon testing, the internal consistency reliability (Cronbach's  $\alpha$ ) of the scale reached .88, indicating excellent reliability.

#### (3) Open-Ended Qualitative Questionnaire

Open-ended questions were established at the end of the questionnaire (e.g., "What specific impacts did the STEAM practical course this semester have on your learning? What difficulties did you encounter and how did you overcome them?") to collect genuine student feedback as a supplement and explanation for the quantitative data.

### 4. Data Processing and Analysis

After excluding invalid questionnaires, the collected quantitative data were imported into SPSS statistical software for processing. Descriptive statistics (mean, standard deviation, percentage) were used to present the current distribution of data, and the Independent-Samples *t*-test was utilized to compare whether the differences in learning outcome scores between the experimental and control groups reached a significant level. Qualitative data were subjected to content analysis for preliminary keyword coding and thematic categorization.

## IV. Results and Discussion

### 1. Quantitative Analysis of Overall Learning Outcomes and Satisfaction

At the end of the semester, after testing the 132 students in both groups, an independent-samples *t*-test analysis was conducted. As shown in Table 3, students in the experimental group (integrating STEAM teaching) achieved a high average score of 4.510 (out of 5, SD = 0.42) in overall learning outcome satisfaction, while the control group (traditional teaching) averaged 4.369 (SD = 0.51). The difference between the two groups reached statistical significance ( $t = -1.745, p < 0.05$ ).

**Table 3.** Independent-Samples *t*-Test Analysis of Overall Learning Outcome Satisfaction between Experimental and Control Groups

Group	Sample Size (N)	Mean (M)	Standard Deviation (SD)	<i>t</i> Value	<i>p</i> Value
Control Group (Traditional)	62	4.369	0.51	-1.745	0.043*
Experimental Group (STEAM)	70	4.510	0.42		

註：  $p < .05$

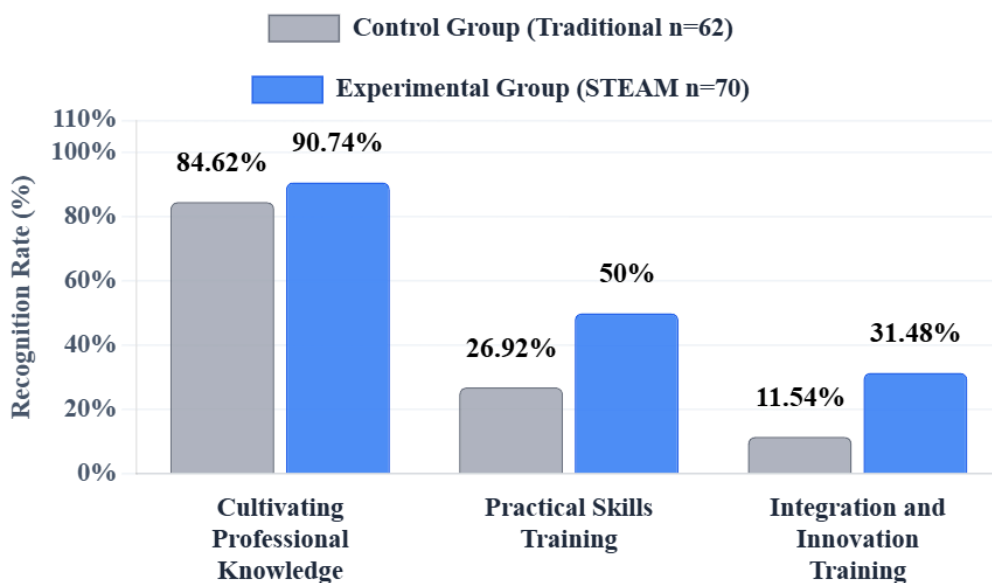
This result strongly indicates that transforming the course from "teacher's one-way lecture" to "students' active project implementation" via the STEAM model can significantly enhance freshmen's engagement in engineering courses, their evaluation of the practicality of teaching materials, and overall learning satisfaction. While traditional teaching maintained a moderately high level of satisfaction (4.369), STEAM teaching broke through the bottleneck of purely theoretical courses, propelling students' satisfaction toward excellence (4.510).

### 2. In-depth Analysis of Differences in Core Competency Recognition

To more precisely analyze which specific competencies STEAM teaching enhanced in students, this study isolated the three core competency indicators from the questionnaire: "Cultivating Professional Knowledge," "Practical Skills Training," and "Integration and Innovation Training." The percentages of students in both groups who answered "Agree" and "Strongly Agree" for these items were calculated, with the results shown in Table 4 and Figure 2.

**Table 4.** Comparison of Core Competency Recognition between Experimental and Control Groups

Core Competency Indicator	Control Group Recognition (n=62)	Experimental Group Recognition (n=70)	Margin of Difference
Cultivating Professional Knowledge	84.62%	90.74%	+6.12%
Practical Skills Training	26.92%	50.00%	+23.08%
Integration and Innovation Training	11.54%	31.48%	+19.94%



**Figure 2.** Bar Chart Comparing Core Competency Recognition between Experimental and Control Groups

Combining the macroscopic and microscopic data from Table 3 and Figure 2, this study derived three academic implications highly inspiring for engineering education:

**(1) Consolidation and Deepening of Professional Knowledge (Breaking the Myth of Time Crowding out)**

Many engineering scholars worry that introducing activity-based STEAM will crowd out the time originally intended for lecturing theories, leading to a weak foundation. However, the data show that the control group had an 84.62% recognition rate in "Cultivating Professional Knowledge," proving that the traditional lecture method does have a baseline utility. Yet, the experimental group not only did not regress but further increased this proportion to 90.74% (an increase of 6.12%). This implies that the process of "actively referencing textbooks to find knowledge in order to solve practical problems" in STEAM teaching did not weaken the theoretical foundation. Instead, it allowed students to verify the authenticity of abstract optical theories through hands-on practice, transforming dead knowledge into portable living knowledge, achieving deeper constructive learning.

**(2) Significant Leap in Practical Skills (Bridging the Hands-on Gap)**

A shocking disparity appeared in the "Practical Skills Training" indicator. Only 26.92% of the control group students agreed that the traditional course was helpful to their "practical hands-on ability," which completely highlights the severe limitations of drawing circuit diagrams on a blackboard and engaging in armchair strategy. In contrast, the experimental group—after personally experiencing finding components, operating soldering irons to weld LED modules, and using wire strippers and multimeters for debugging—saw their practical skills recognition nearly double to 50.00% (a jump of 23.08%). This proves that the STEAM course successfully helped students overcome the psychological barrier of "fear of breaking equipment" and established the hands-on confidence and self-efficacy essential for engineers.

**(3) Breakthrough in Integration and Innovative Thinking (Awakening of Higher-Order Cognitive Abilities)**

In Bloom's Taxonomy of educational objectives, "Create" (Integration and Innovation) belongs to the highest level of cognitive ability. Because the outcomes of traditional, strictly scheduled practicums are

predetermined, the control group's recognition of this item was dismally low (only 11.54%). However, after experiencing STEAM teamwork-brainstorming themes from scratch, designing appearances, overcoming technical interference, and producing unique physical "Solar Photovoltaic" or "Optical Communication" projects—the experimental group's recognition surged to 31.48% (an increase of 19.94%). This amply demonstrates the powerful energy of STEAM education in stimulating cross-disciplinary creativity and cultivating formidable capabilities when facing unknown engineering challenges among freshmen.

### 3. Qualitative Feedback Analysis and Comprehensive Discussion

To triangulate with the quantitative data, this study summarized the qualitative feedback from experimental group students in the end-of-semester open-ended questionnaire. The majority of the feedback strongly echoed the quantitative results and pinpointed the key factors for the successful operation of the STEAM teaching method.

Firstly, regarding the **connection between practical skills and knowledge**, a student explicitly stated: *"In high school, I thought the electrical engineering formula  $V=IR$  was just for passing exams, but when I really had to make the LED lighting fixture I assembled light up, I realized that if I bought the wrong wattage for the resistor, the bulb would burn out. Every calculation is related to the success or failure of the project. This gave me a renewed understanding of the meaning of formulas."* This feedback perfectly corroborates the argument of King (2016): the process of seamlessly connecting Science (S) and Mathematics (M) theories to an iterative engineering design model is exactly the panacea for breaking the "theory-practice gap."

Secondly, regarding the **catalytic effect and flow experience of the Arts (A) element**, student feedback mentioned: *"The most special thing about this class is that we also had to pay attention to the aesthetics of the project. For the final presentation, we spent a lot of time discussing how to hide the ugly wires inside the acrylic board, and even used a 360-degree camera to record our production process. Although we often discussed until we lost track of time, the moment we finally finished it was super fulfilling, and I also learned how to communicate with classmates who have different opinions."* This statement reveals a blind spot often overlooked in traditional engineering education—the neglect of humanities, aesthetics, and communication skills.

The addition of Arts (A) and aesthetic design forced these freshmen to step out of their comfort zones and engage in extensive cross-disciplinary communication and compromise. This not only effectively remedied the shortcoming commonly criticized by the industry that engineering students "only know how to do math but not how to express and communicate," but also transformed the cold implementation of optical principles into a learning journey full of Flow Experience and interpersonal interaction.

## V. Conclusion and Suggestions

### 1. Conclusion

Based on improving the learning pain points of freshman engineering students, this study integrated the STEAM innovative cross-disciplinary teaching method into the "Introduction to Optic-Electrical Engineering" course. After a semester of quasi-experimental research and data analysis, three major conclusions were reached:

#### (1) Completely Overturning the Learning Landscape and Enhancing Overall Satisfaction

The STEAM project-based teaching method can significantly enhance students' learning motivation and class participation. The experimental group's overall effectiveness score reached 4.51, statistically significantly outperforming the control group (4.369) which used traditional lecture-based teaching.

#### (2) Breaking the Barrier between Theory and Practice, Effectively Bridging the Theory-Practice Gap

STEAM teaching did not weaken theoretical learning due to manual activities (professional knowledge

recognition reached 90.74%, superior to the control group). It accurately struck the pain points of traditional courses, explosively increasing "practical skills" recognition by 23.08% and the higher-order "integration and innovation" ability recognition by 19.94%, demonstrating an astonishing practical conversion rate.

### **(3) Successfully Implementing Initial Exploration of Higher Engineering Practice**

Through project groups of 3 to 6 people, freshmen were able to manually produce concrete products such as solar energy, optical communication, and LED lighting, combined with artistic design and presentation. This move successfully laid a professional foundational capability for system integration, troubleshooting, and teamwork for these future engineers during their first year of university.

## **2. Suggestions**

Based on the fruitful results of this study, the following specific suggestions are proposed for future frontline teaching practice and subsequent academic research:

### **(1) Suggestions for Teaching Practice (Downward Rooting and Industry Linking)**

It is strongly recommended that engineering colleges in domestic vocational and general universities actively root the STEAM project implementation model downwards into the freshman introductory courses of various departments. Additionally, when designing project themes, instructors should closely tie them to the local national industrial development trends (such as Taiwan's semiconductor, green energy, and optical communication industries), allowing students to foresee their future career blueprints during implementation, thereby deepening their professional identity early and effectively reducing the dropout rate.

### **(2) Suggestions for Future Research (Introducing Emerging Technologies and Longitudinal Tracking)**

This study verified the outstanding short-term effectiveness of STEAM teaching. Future research can further integrate advanced emerging digital tools (such as Virtual Reality (VR) simulators or Generative AI assisted programming) to explore the specific impact of these technological tools intervening in the STEAM process on students' "cognitive load." Concurrently, it is suggested to adopt a longitudinal study to track these students who experienced the STEAM freshman course, observing whether their problem-solving abilities are significantly superior to other students when facing advanced capstone projects in their junior or senior years.

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