Investigating the Impact of Interdisciplinary Experience on the Learning Performance of Industrial Design Students

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Abstract
This study explores the impact of three different interdisciplinary experience student groups on the learning outcomes of industrial design students (without interdisciplinary learning process, participating in interdisciplinary activity courses, and participating in complete interdisciplinary courses). To understand what kind of learning experience can effectively improve students' cross-disciplinary teamwork ability and the differences in the complete product development process. In the research, semi-structured interview questionnaires were used to collect, analyze, and summarize the interviewees' learning process, practical operation, and other issues. Quantitative evaluation is carried out through cross-disciplinary basic ability analysis (communication, reflection, practice) and product development learning effectiveness (Rubrics scale) formulated by professional teachers. Qualitative interviews are also conducted with students with different interdisciplinary learning experiences, recording the students' special presentations and digs into the situation of team interaction. The analysis was carried out with one-way analysis of variance, descriptive statistics, and interview coding. The results show that the teams of "participating in interdisciplinary activity courses" and "participating in complete interdisciplinary courses" are better than the teams with "no interdisciplinary learning process", in terms of interdisciplinary basic core competencies and product development. No significant difference was shown between "participating in an interdisciplinary activity course" and "participating in a complete interdisciplinary course". Therefore, students of the Department of Industrial Design can cooperate with different faculties and schools by participating in active cross-disciplinary courses and improve their participation in cross-disciplinary teamwork through learning experiences.

Keywords: Interdisciplinary Experience, Communication, Reflection, Practice, Rubrics Scale

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1. Introduction

1.1 Background

Industrial designers today are facing a more rapidly changing, diverse, and complex industrial environment. The fields of innovation include big data, artificial intelligence, machine automation, service design and user experience design, etc. Designers today often establish diverse collaborative teams to research and solve novel and difficult problems through interdisciplinary approaches (Ledford, 2015). Shandas, V. (2016) and they believe that people from different disciplines can solve complex issues through different thinking and knowledge. Designers use interdisciplinary capabilities to adapt to the needs of different professional fields, thus avoiding incomplete thinking caused by the solidification of ideas in a single field. In other words, interdisciplinary designers of design thinking must have the ability to solve complex interdisciplinary problems.

1.2 Motivation

Eagan, Cook, and Joeres (2002) mentioned that by teaching interdisciplinary communication skills between various disciplines, tolerance of perspectives from other professional fields, self-examination, evaluation, reflection, and teamwork can help students to overcome barriers in interdisciplinary research and cooperation. The current knowledge cycle is getting shorter and shorter and requires the integration of different knowledge backgrounds. Personnel training tends to be more conceptual skills, communication skills, teamwork, and creativity. At present, in the university education system, we are still faced with academic majors discussing too deeply a single subject and ignoring the complex issues of training students to face different fields. Cha Jianzhong (2008) pointed out that there are three major problems in the teaching plan of today's university education:

1. Too much emphasis on theory and practice, the teaching content is updated slowly and cannot keep up with the development of the industry.
2. The lack of diversity and simplification of teaching methods limit the creativity of teachers and students.
3. Too much emphasis is placed on teachers' lectures in the classroom and the link of students' active learning and practice is ignored.

Furthermore, teachers can try to change different teaching methods to meet the actual teaching situation and the learning needs of students to pursue the best learning effect as the goal. Therefore, to provide students with reflectional educational models and related learning activities are important to develop their skills and competencies. It can be said that interdisciplinary education is an important source for students to acquire interdisciplinary ability.

1.3 Purpose

This research takes the senior students majoring in industrial design as the research subject. The study explores how interdisciplinary teaching methods can effectively cultivate students' ability to solve complex problems through different interdisciplinary learning experiences when facing complex problems. The students in the team have professional knowledge in diverse fields and are observed what problems they will encounter during the product development process. Through this research, the purpose of improving future interdisciplinary curriculum planning can be achieved.

Therefore, the purpose of this study is to explore the three following aims:

(1) To discuss which learning experience (no interdisciplinary learning process, participation in interdisciplinary activity courses, and participation in complete interdisciplinary courses) can improve the learning efficiency of students in the Department of Industrial Design under different interdisciplinary learning experiences.
(2) To understand the differences in interdisciplinary abilities of industrial design students with different interdisciplinary learning experiences.
(3) To discuss the differences in the product development process of students in the industrial design department and verify the impact of different interdisciplinary learning experiences.

The importance of interdisciplinary education has gradually become recognizable by the academia and professionals. Related theoretical research is maturing. In this way, students' creative contribution skills and abilities can be cultivated, and students' competitiveness can be effectively improved.

2. Literature review

2.1 Interdisciplinary definitions

Stember (1991) stated that interdisciplinary consists at least two collaborators, as well as the basic elements of two disciplines and problem- solving in a certain collaborative way of a certain field. The goal of a single discipline is narrow, and its main purpose is to explain within the confines of its own field thus limiting broad thinking on issues as knowledge is updated (Moran, 2002). Multidisciplinary occurs when the solution to a problem requires information from two or more fields of science or knowledge rather than changing or enriching the original disciplines (Piaget, 1972). Interdisciplinary cooperation refers to the integration of knowledge owned by a single individual or group, through theories, concepts, viewpoints, tools, technologies, data, integration, etc., to solve complex problems outside the scope and respond to rapidly changing society needs. Interdisciplinary technology is not only important for students to study any single subject or solve problems in an integrated manner, it also enriches students' lifelong learning habits, academic skills, and personal growth. From the above literature, it can be concluded that these common points all emphasize the integration of individual or group knowledge and technology to solve problems and enhance each other's multiple capabilities to cope with rapidly changing needs.

2.2 Diverse interdisciplinary curriculum

Interdisciplinarity has become part of the contemporary university's approach to research and course knowledge. Interdisciplinary collaborations are beneficial for the creative development of teams because they can pool more resources and expertise in the group (Baker, Day & Salas, 2006). Stanford breaks down institutional distances and brings together researchers with diverse expertise to encourage students to conduct research that crosses traditional boundaries. Diverse capabilities lead to innovative ideas and combine industrial designers, scientists, and engineers in various ways for a wide range of research. Millar

(2016) restructured their curriculum in various ways to incorporate interdisciplinarity, develop skills across disciplinary boundaries and address major world issues.

2.3 Interdisciplinary Design

The life cycle of a product can be divided into three stages: design, engineering, and sales, but this means that the three operate independently. On the contrary, design, business, or engineering technology should be integrated among the three (Buxton, 2010). Designers should have cognitive abilities, that is, the ability to reflect, communicate, discover, and solve problems. The ability to innovate and practice means that designers could propose new concepts and bridge interdisciplinary concepts. Weil and Mayfield (2020) propose that ID's MDes program considers the range of topics in the design curriculum and the various skill levels that students develop. The main claims that the curriculum should develop student understanding in:

(1) Covering the breadth and depth:
Designers' Learning is focused on understanding production as the field of design matures and expands and the practicality of specialization is called into question while creatively finding opportunities to produce new things.

(2) Integrating application and theory:
Designers should not be limited to personal experience because design solves problems far beyond personal experience and intuition and focusing on the bridge between theory and practice helps students learn to construct their own ideas.

(3) Managing diverse talents and perspectives:
Designers can broaden everyone's dialogue, vision, and can mediate collaboration between different fields.

3. Methodology

3.1 Extracting basic interdisciplinary capabilities from literature.

Self, Evans, Jun, & Southee (2019) et al. provided seven criteria for evaluating interdisciplinary learning and organized them into Table 1 for the criteria for the nature of interdisciplinary competence. Wilhelmsson et al. (2012) also emphasized the importance of communication, reflection, and practice for interdisciplinary learning. Mahy, I., & Zahedi, M. (2010) et al. use an interdisciplinary approach to integrate artists and managers to complete the artistic creation process and transform the collaboration into practice and reflection. This survey refers to the questionnaire of Lattuca et al. (2012) and based on the conceptual framework of seven standards provided by Self, Evans, Jun Southee et al. (2019) (Table 1) to edit the questionnaire of this study. This research adopts the method of in-depth interview and literature to extract the basic interdisciplinary ability including communication, reflection, and practice (Table 2). This study further designed the research process through the principle of "island of knowledge" proposed by Fruchter & Emery, (1999) (Figure 1).

Interdisciplinary Course Interview Questionnaire is a semi-structured questionnaire edited through expert interviews. The purpose is to understand the differences in the teamwork styles of industrial design students with different interdisciplinary learning experiences in the product development process. Teachers use the Rubrics scale to evaluate students' Grading of Graduation Project Works. The scoring principle of the five-level Likert scale is "5 points for excellent, 4 points for ability, 3 points for general, 2 points for improvement, and 1 point for incompleteness". The higher the student's score, the better the student's ability in this area. Finally, the evaluation data was analyzed by SPSS statistical software released by IBM, and statistical methods such as correlation and one-way analysis of variance (ANOVA) were used to analyze whether there were significant differences between different groups.

Table 1: Seven criteria for evaluating interdisciplinary learning. (Self, Evans, Jun, & Southee (2019) et al.)

Criteria to Assess Interdisciplinarity	Description
C01.Awareness of Disciplinarity	Work being well grounded in disciplines which it draws. The idea that certain level of disciplinary knowledge required to effectively integrate perspectives, methods & practices of two or more disciplines to achieve specific goal.
C02. Appreciation of Disciplinary Perspectives	Process of fostering disciplinary knowledge & appreciation of disciplinary perspectives. Moving from general knowledge of discipline to more specific knowledge of how each of its elements informs insights into the problem.
C03. Recognition of Disciplinary Limitations	Means through which interdisciplinary competences may be measured. Critical reflection upon and awareness of one's own field of study.
C04. Appropriateness of Interdisciplinarity	Means to solve different problems in various situations. Students able to develop ability to effectively evaluate effectiveness of interdisciplinary work.
C05. Finding Common Ground	Ability to dynamically modify one's own perspectives, world view & expectations to accommodate those of others.
C06. Reflexivity	Ability to reflect upon one's own choices for defining a given problem; how these choices may influence framing & solution development.
C07. Integrative Skill	Ability to synthesize & integrate knowledge in order to provide more comprehensive understanding of problem and/or possible solutions.

Table 2: Three interdisciplinary core competencies.

Interdisciplinary Core Competencies	Description
Ability to communicate	The ability to coordinate and synthesize information, views or insights from different areas of knowledge to effectively exchange knowledge and ideas with other professionals.
Ability to reflect	The ability to reflect in the process of cooperation with different professional teams and experts to generate new ideas and proactively search for possible solutions.
Ability to practice	Practical ability to collaborate using expertise from different disciplines and work with teams to solve complex problems.

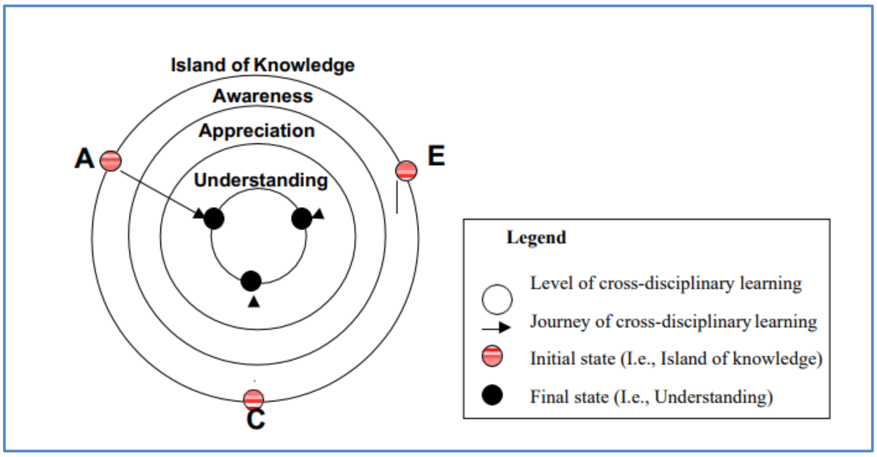

Figure 1: Four-Tiered Classification for Cross-Disciplinary Learning Assessment (Fruchter et al. 1999).

3.2 Participants

This study is divided into three groups of students with different interdisciplinary learning experience:

(1) Group **a** without interdisciplinary experience:
The senior industry design students have no interdisciplinary learning experience to roughly understand the cross -domain meaning.
(2) Group **b** has some interdisciplinary experience:
The senior industrial design students have participated in the interdisciplinary curriculum and different departments to fulfill the complete design proposal experience in the study process.
(3) Group **c** has a complete interdisciplinary experience:
The senior students of the Department of Industrial Design have fully participated in the interdisciplinary courses of Tatung University, including business majors, engineering majors, and design majors.

3.3 In-depth interview

In this study, those who met the following three conditions were interviewed.

(1) The interviewed group has experience in compliance with the corresponding learning background.
(2) The interviewed group has a complete team cooperation experience in the learning process.
(3) The interviewed groups have a preliminary understanding of interdisciplinary capabilities.

A total of 26 senior students of the Department of Industrial Design in this study were interviewed. The respondents were willing to participate and share their learning experience. 16 of them had cross-disciplinary cooperation experience (8 students participated in interdisciplinary activities, and 8 other students participated in the complete interdisciplinary courses) and 10 students have not participated in cross-disciplinary studies. From the interviews of each stage, we will understand and record the discussions between the respondents and the team.

This study adopted (Thomas, 2000) procedure based on the "inductive method" to analyze the student interview data to:

1. Condense extensive and varied raw text data into a brief, summary format.
2. Establish clear links between the research objectives and the summary findings derived from the raw data and to ensure these links are both transparent (able to be demonstrated to others) and defensible (justifiable given the objectives of the research).
3. Develop of model or theory about the underlying structure of experiences or processes which are evident in the text (raw data).

In order to improve the coding efficiency, NVivo 11 is finally used as the coding software.

3.4 Product rating scale development

The purpose of the scale is to evaluate the kind of teaching that can effectively improve students' learning benefits. Rubrics is a meter used to evaluate diverse factors and subjective learning benefits and provide teaching direction and feedback. The Rubrics assessment method is suitable for interdisciplinary student learning outcome-oriented assessment. It is different from traditional quantitative data and can allow us to better understand the learning direction that students should adjust to strengthen their learning outcomes. This research is based on the Rubrics scale N22W329 (Rcampus, 2023) of the design course, General Rubrics for Art/Craft Assignments Rubrics DXW38XB (Rcampus, 2023) and designed five items including design concept and value, differentiation and innovation, feasibility, aesthetic appearance, and project completeness.

4. Analysis

4.1 Interview Coding Analysis of Participants

Through in-depth interviews with 26 industrial design seniors who belong to three different interdisciplinary learning experience groups, the interview data collection and coding are based on the interdisciplinary core competencies sorted out from the literature. Three factors extracted through selective coding include communication, reflection, and practice.

The 26 students were divided into (**a**), (**b**), and (**c**) three groups and numbered according to no interdisciplinary learning experience, interdisciplinary learning experience and complete interdisciplinary learning experience. For example, **a1** represents the first student in group **a** who has no interdisciplinary learning experience. The main category and subcategory details of the interdisciplinary core competence are extracted from the verbatim transcripts of the interviewers through selective coding and axial coding. In team communication and interaction, group **c** has the most mentions and group **a** has the least number of mentions. In the efficiency in learning, group **c** has the most mentions and group **a** has the least. In the feeling of inadequacy in learning, group **a** has the most mentions and group **c** has the least. In the feedback during learning, group **c** has the most mentions and group **a** has the lowest. In the teacher's opinion, group **c** has the most mentions and group **a** has the least number of mentions. In teamwork, group **c** has the most mentions and group **a** has the least.

Through the sub-item analysis of the core competency of team communication, the results show that group (**a**) and group (**b**) can communicate quickly within the team, the reason is that the team members of the two teams have the same major subjects, and the students only have partial interdisciplinary learning experience or no interdisciplinary learning experience, but the influence of each student's "personal style difference" factor leads to "communication difficulties" within the team.

In addition, the lack of students with different majors and professional backgrounds in the group is the main reason for the negative impact of "multiple thinking" and "project completion". The above effects cause the selection of sub-items encoded in the main axis of the core competence of reflection "learning regret" is extracted more often. Because of the complete interdisciplinary learning experience, group (**c**) can communicate well in the three aspects of "professional opinion", " multiple thinking " and "product structure". On the other hand, group (**c**) has communication difficulties in four aspects of "technical terms", "cognitive differences", "process conflicts" and "low participation". The reason is that team members have complete interdisciplinary learning experience. The analysis results of the selective coding and axial coding of the interviewed students are shown in Table 3.

Table 3: The analysis results of the selective coding and axial coding.

Coding		Group		
Selective coding	Axial coding	(**a**)	(**b**)	(**c**)
communication	Team communication	*	**	***
	Team interaction	*	**	***
reflection	Efficiency in learning	*	**	***
	Feel inadequate in learning	***	**	*
	Feedback during learning	*	**	***
	Teacher's opinion	*	**	***
practice	Teamwork	*	**	***
	Difficulties within the team	*	**	***

Number of mentions: *--Most, **--Middle, *--Lowest**

The results of the interview coding analysis of product development and design schemes show that the four main difficulties in group (**a**) are "differences in innovative design schemes", "limited thinking in design schemes", "feasibility of design schemes", and "developmental suggestions for design schemes."

The main reason is that the homogeneity of team members without relevant interdisciplinary experience is limited in " multiple thinking ". Moreover, group **a** lacks other professional ability and can only screen proposals within the scope of existing ability. Therefore, the " multiple thinking " of early product concepts is limited. "Data collection of design schemes", "differences in innovative design schemes", "limited thinking of design schemes", "feasibility of design schemes" and " developmental suggestions for design schemes " are the main aspects of group (**b**)'s difficulty. The main reason is that group members have interdisciplinary experience, but students' learning experience is still dominated by a single discipline. When team members execute product proposals, the "data collection" in the "pre-concept of product design" will be limited. "Professional communication of design proposals", "differences in innovative design schemes", "conflicts in design proposal process", and "convergence of design proposal problems" are the main difficulties of group (**c**). The reason for the difficulty is that the group members have complete interdisciplinary learning experience, which creates conflicts between different backgrounds. Team members need more time to adjust and communicate in the "pre-concept of product design". The results of the interview coding analysis of group of a, b and c are shown in Table 4, 5 and 6.

Table 4: The coding analysis results of group a in product development and design schemes.

Coding		(**a**)
Selective coding	Axial coding	Reason
Reflection	Differences in innovative design schemes	Limited in " multiple thinking "
	imited thinking in design schemes	
Practice	Feasibility of design schemes	Lack of other professional ability
	Developmental suggestions for design schemes	

Table 5: The coding analysis results of group b in product development and design schemes.

Coding		(**b**)
Selective coding	Axial coding	Reason
Reflection	Differences in innovative design schemes	Limited in " multiple thinking "
	limited thinking in design schemes	
Practice	Feasibility of design schemes	Students' learning experience is still dominated by a single discipline
	Developmental suggestions for design schemes	
	Data collection of design schemes	

Table 6: The coding analysis results of group c in product development and design schemes.

Coding		(**c**)
Selective coding	Axial coding	Reason
Communication	Professional communication of design proposals	Group members have completed interdisciplinary learning experience which creates conflicts between different backgrounds.
	Conflicts in design proposal process	
	Convergence of design proposal problems	
Reflection	Differences in innovative design schemes	Students' learning experience is still dominated by a single discipline

4.2 Product Development Rubics Rating Scale

In this study, the scores of the Rubrics scale were analyzed by one-way analysis of variance. The results show that there are significant differences between group **c** and group **a** in terms of “design concept and value”, “differentiation and innovation”, “feasibility”, “project completeness”**,** but there is no significant difference in “aesthetic”. In addition, there was no significant difference between group **a** and group **b** as well as between group **b** and group **c** in the five Rubrics scale scoring items. The ANOVA results of the Rubrics scores are shown in Table 7.

Table 7: The ANOVA results of the Rubrics scores.

ANOVA of Rubrics Scale Scores			
Variable	**Group**		**P -value**
1.Design concept and value	**c**	**a**	**0.001***
		b	**0.398**
2.Differentiation and innovation	**c**	**a**	**0.001***
		b	**0.828**
3.Feasibility	**c**	**a**	**0.001***
		b	**0.231**
4.Aesthetic	**c**	**a**	**0.772**
		b	**0.589**
5.Project completeness	**c**	**a**	**0.001***
		b	**0.264**

***-Significant**

Further comparison of the average scores of group a, group b, and group c in the five scoring items of the Rubrics scale shows that the average scores of group c and group b are higher than those of group a. The results of the comparison between groups and the mean of the Rubrics scale scores are shown in Figure 2.

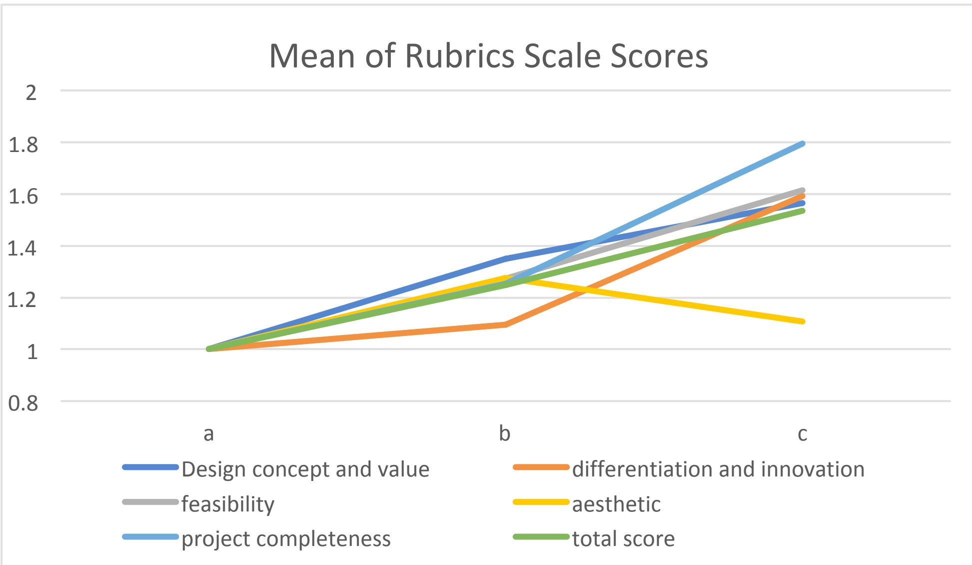

Figure 2: The results of the comparison between groups and the mean of the Rubrics scale scores.

5. Conclusions and Recommendations

5.1 Conclusion

1. In terms of student learning effectiveness, there is a significant difference between students with "interdisciplinary learning experience" and "no interdisciplinary learning experience." After the main axis coding analysis, the choice coding analysis, and the qualitative interview, the research results reveal the following conclusions. The efficiency and feedback of learning in teamwork and the complete product development process are higher for students with interdisciplinary learning experience than for students without interdisciplinary experience.

   Therefore, actively encouraging students to participate in relevant interdisciplinary activities can enrich students' multiple thinking and break through the limitations of a single major. Diversity in educational background has a positive impact on team success. Multidisciplinary can generate new ideas at the intersection of disciplinary knowledge, while enhancing collaboration and improving research productivity. (Salazar et al., 2012. van Knippenberg, Ginkel & Homan, 2013).

2. Students of the Department of Industrial Design should combine interdisciplinary teams to complete the work when making project works. The average score of the student team with "complete interdisciplinary experience" is higher than that of the other teams in all aspects, except for the score of product aesthetics which is lower than the other groups. Especially in the feasibility and complete implementation of the project, team members from different professional fields can efficiently help in the implementation of the design and the assistance of non-design professional technology. Therefore, when designing students carry out project works and engage in related courses, they should first be introduced to interdisciplinary Experience to improve the efficiency and completeness of project execution. Salazar, Lant, Fiore and Salas (2012) also pointed out that diverse interdisciplinary teams were found to be associated with high productivity and having diverse researchers within the same organization can help improve team performance.

3. Increased participation in interdisciplinary teamwork and true interdisciplinary collaboration is important. It is joint disciplines that solve common problems and continue to help each other, rather than single disciplines solving problems alone (Borrego & Newswander, 2008). Collaboration is needed through a steady phase of course teams, with a focus on designing assessments and activities for multidisciplinary student groups, not just theory or classroom lectures (Hannon et al., 2018). Separate disciplinary structures have a limiting effect on academic collaboration. It should not simply use the department's theory as an interdisciplinary course plan but incorporate collaboration between different areas of expertise so that students fully understand its importance (Davison et al., 2012).

5.2 Recommendations for follow-up research

Regarding the limitations and results of this study, there are still some areas that need to be improved, and the following suggestions are made for future research directions.

1. Due to research limitations such as tracking the long-term learning process, the number of tested samples is relatively insufficient. In the future, the number of tested subjects should be expanded to explore its learning benefits in depth.

2. This study is mainly to explore the impact of different interdisciplinary learning experiences and the effectiveness of interdisciplinary ability training for design students. Future research can include more departments in the scope of the study.
3. The composition of interdisciplinary team members in this study covers business majors, engineering majors, and design majors. Future research can explore how to effectively improve the cooperation model with design majors from the perspective of different departments.
4. Improvements are needed in the studies of product animation, video clips, multimedia software and other related courses in the courses of the Department of Industrial Design to explore whether they can improve students' learning efficiency.

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