What Factors Drive the Improvement of Students' Cross-Disciplinary Innovation Competencies in Engineering-Education Intersection? A Comparative Study of Blended Curriculum Models

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Abstract: Against the backdrop of the deep integration of engineering technology and educational innovation, the cultivation of students' cross-disciplinary innovation competencies has become a core goal of higher education reform. However, empirical research on the effectiveness of blended curriculum models in the engineering-education intersection discipline is still scarce. This study takes three universities in East Asia and Europe as research objects, adopts a mixed research method combining one-way ANOVA and structural equation modeling (SEM), and explores the key variables affecting students' cross-disciplinary innovation competencies in engineering-education intersection programs by comparing the competency differences of students under different blended curriculum models. The study identifies six potential influencing variables: the proportion of project-based learning (PBL) in engineering courses, the number of educational technology integration practice courses, participation in industry-education collaborative innovation internships, the frequency of cross-disciplinary student team collaboration, the implementation of engineering-education interdisciplinary team teaching, and the use of intelligent teaching evaluation tools. The results show that industry-education collaborative innovation internships ($\beta = 0.426$, $p < 0.001$) and educational technology integration practice courses ($\beta = 0.389$, $p < 0.001$) have the most significant positive effects on students' cross-disciplinary innovation competencies, followed by the proportion of PBL in engineering courses ($\beta = 0.278$, $p < 0.01$) and intelligent teaching evaluation tools ($\beta = 0.215$, $p < 0.05$). The frequency of cross-disciplinary team collaboration and interdisciplinary team teaching have no direct significant effect but play a significant moderating role in the above core variables. The research conclusions are verified in universities with different educational systems and cultural backgrounds, showing high objectivity and universality. This study constructs a "practice-driven, technology-supported" curriculum design framework for the engineering-education intersection discipline, which provides a theoretical basis and practical reference for the cultivation of cross-disciplinary innovation talents in related fields.

Keywords: Engineering-education intersection; Cross-disciplinary innovation competencies; Blended curriculum model; Industry-education collaboration; Educational technology

1 Introduction

In the era of the digital economy, the deep integration of engineering technology and educational innovation has spawned a series of emerging cross-disciplinary fields such as educational robotics, intelligent educational equipment research and development, and engineering education informatization [10]. The development of these fields requires talents with both solid engineering technical literacy and advanced educational innovation concepts, and their core competency is cross-disciplinary innovation competency–the ability to integrate engineering technology knowledge and educational theory to solve complex practical problems in the field of education [12]. However, the traditional disciplinary-oriented curriculum model has obvious limitations in cultivating such talents: engineering courses focus on technical training and lack the connection with educational application scenarios, while education courses focus on theoretical teaching and lack the integration with engineering technology means [7]. This disconnection leads to the fact that students majoring in

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engineering-education intersection often have difficulties in realizing the cross-application of knowledge between disciplines, and their cross-disciplinary innovation competencies are difficult to meet the actual needs of the industry.

In response to this problem, many universities around the world have tried to construct blended curriculum models for the engineering-education intersection discipline, integrating engineering technology courses, educational theory courses, and practical application links [12]. For example, the University of Twente in the Netherlands has set up a "Educational Technology and Engineering" program, which combines mechanical engineering, computer science with educational psychology, and designs project-based learning (PBL) projects around the research and development of intelligent teaching equipment; East China Normal University in China has launched an engineering-education intersection program, which integrates educational technology courses with electrical engineering courses and carries out industry-education collaborative internships with educational equipment enterprises. However, due to the differences in educational concepts, curriculum resources and industry cooperation conditions, the design of blended curriculum models in various universities is quite different, and there is no consistent conclusion on which curriculum elements and their combination can effectively improve students' cross-disciplinary innovation competencies [6].

Existing research on cross-disciplinary curriculum design mostly focuses on single disciplines such as design, business and engineering [14], and few studies target the engineering-education intersection discipline with the dual attributes of "engineering technology" and "educational service". In terms of research methods, most studies adopt qualitative analysis or simple quantitative comparison, and lack the in-depth exploration of the causal relationship and moderating effect between curriculum variables and students' cross-disciplinary competencies [12]. In addition, the existing research mostly ignores the role of intelligent educational technology in the blended curriculum model, such as intelligent teaching evaluation tools and online collaborative learning platforms, which are important support for the cultivation of cross-disciplinary innovation competencies in the digital age [15].

To fill the above research gaps, this study takes the engineering-education intersection discipline as the research perspective, takes three universities with different educational systems and cultural backgrounds as the research objects, and uses a mixed research method combining one-way ANOVA and structural equation modeling to explore the following core research questions: (1) What are the key curriculum variables that affect students' cross-disciplinary innovation competencies in the engineering-education intersection discipline? (2) What are the intensity and path of the influence of each core variable on students' cross-disciplinary innovation competencies? (3) What kind of blended curriculum model can effectively cultivate students' cross-disciplinary innovation competencies in the engineering-education intersection discipline?

The marginal contributions of this study are as follows: First, it expands the research scope of cross-disciplinary curriculum design to the engineering-education intersection discipline, and enriches the theoretical research on talent cultivation in emerging cross-disciplinary fields; Second, it introduces intelligent teaching evaluation tools as a new curriculum variable, and constructs a more comprehensive influencing factor model of cross-disciplinary innovation competencies; Third, it verifies the moderating effect of cross-disciplinary team collaboration and interdisciplinary team teaching, and reveals the internal mechanism of curriculum variables on the cultivation of cross-disciplinary innovation competencies; Fourth, it constructs a "practice-driven, technology-supported" blended curriculum design framework, which provides a practical reference for universities to design engineering-education intersection curriculum models.

2 Literature Review and Theoretical Framework

2.1 Concept Definition

2.1.1 Engineering-Education Intersection Discipline

The engineering-education intersection discipline is an emerging cross-disciplinary field formed by the mutual penetration and integration of engineering science, educational science and information technology [2]. Its research object is the application of engineering technology in the field of education, and its core research content includes the research and development of educational equipment, the design of intelligent teaching systems, the construction of engineering education informatization platforms, etc. This discipline has the dual characteristics of engineering and education: engineering is the technical foundation, requiring students to master solid engineering knowledge and technical skills such as mechanical design, electronic information and computer programming; education is the application orientation, requiring students to master educational theory, teaching design and educational evaluation methods [5].

2.1.2 Cross-Disciplinary Innovation Competencies

Based on the research of Xu and Wu [14] and Borrego et al. [12], this study defines the cross-disciplinary innovation competencies of students majoring in engineering-education intersection as the comprehensive ability to integrate engineering technology knowledge and educational theory, identify practical problems in the field of education, and design innovative solutions with engineering technology means. Combined with the characteristics of the engineering-education intersection discipline, this study decomposes cross-disciplinary innovation competencies into four sub-competencies: (1) Cross-disciplinary knowledge integration ability: the ability to connect engineering technology knowledge and educational theory, and form a systematic cross-disciplinary knowledge system; (2) Educational problem engineering transformation ability: the ability to transform practical educational problems into engineering technical problems that can be solved with technical means; (3) Innovative design and development ability: the ability to design and develop educational equipment, teaching systems and other innovative products combining engineering technology and educational needs; (4) Cross-disciplinary communication and collaboration ability: the ability to communicate and collaborate with professionals in engineering, education and other fields to complete cross-disciplinary innovation projects.

2.1.3 Blended Curriculum Model

Blended curriculum model refers to a curriculum design form that integrates different types of curriculum elements (theoretical courses, practical courses, internships, etc.), teaching methods (lecture, PBL, team teaching, etc.) and teaching tools (intelligent evaluation tools, online learning platforms, etc.) according to the talent cultivation goals of the cross-disciplinary discipline [4]. For the engineering-education intersection discipline, the blended curriculum model is characterized by the organic integration of engineering technology curriculum modules, educational theory curriculum modules and practical application curriculum modules, and the combination of offline classroom teaching and online collaborative learning, classroom theoretical teaching and industry practical training.

2.2 Literature Review

2.2.1 Research on Cross-Disciplinary Curriculum Design

Foreign research on cross-disciplinary curriculum design started early, and scholars have proposed a variety of curriculum design models and influencing factors. Lindvig and Ulriksen [8] divided cross-disciplinary curriculum models into three types: “pearl on the string”, “zipper” and “snowflake” through literature analysis, and pointed out that the curriculum model centered on specific social problems is more conducive to the cultivation of students’ cross-disciplinary competencies. Lattuca et al. [6] found through empirical research that foundational courses of other disciplines, interdisciplinary practice courses and off-campus internships are the key elements affecting students’ cross-disciplinary competencies. Xu and Wu [14] took two East Asian universities as research objects, and found that interdisciplinary integration practice courses and off-campus internships at the beginning of the curriculum have a significant positive effect on students’ cross-disciplinary integration competencies.

Domestic research on cross-disciplinary curriculum design is mostly focused on the exploration of curriculum models and practical experience summaries. Zhang et al. [13] constructed a cross-disciplinary curriculum model for engineering majors based on industry-education integration, and verified its effectiveness through teaching practice. Gao et al. [6] took educational technology majors as the research object, and found that project-based learning and industry-education collaborative internships can effectively improve students’ cross-disciplinary application ability. However, most of these studies focus on single disciplines or traditional cross-disciplinary fields, and few studies target the engineering-education intersection discipline.

2.2.2 Research on the Cultivation of Cross-Disciplinary Innovation Competencies

Scholars at home and abroad have conducted extensive research on the cultivation of cross-disciplinary innovation competencies from the perspectives of teaching methods, practical links and team collaboration. Brassler and Dettmers [3] found that interdisciplinary problem-based learning is more effective than project-based learning in cultivating students’ cross-disciplinary competencies. Pollard et al. [9] pointed out that interdisciplinary team teaching can effectively improve students’ cross-disciplinary thinking and innovation ability. Chen et al. [15] found through empirical research that intelligent teaching tools can optimize the process of cross-disciplinary knowledge acquisition and improve students’ innovation ability. In the field of engineering-education intersection, Li and Wang [5] proposed that the cultivation of cross-disciplinary innovation competencies needs to focus on the integration of engineering technology and educational practice, but there is a lack of empirical research to verify it.

2.2.3 Research on the Integration of Engineering and Education

Research on the integration of engineering and education is mainly focused on the construction of engineering education curriculum systems and the application of educational technology in engineering education [12]. UNESCO [10] issued a report pointing out that the integration of engineering technology and educational innovation is an important trend in the development of global higher education, and universities should strengthen the construction of engineering-education intersection curriculum systems. Smith et al. [11] took the University of Twente as a case, and analyzed the curriculum design experience of the engineering-education intersection program, and found that industry-education collaboration is the key to the success of the program. However, these studies mostly focus on the macro level of curriculum construction, and lack the micro level of exploration on the relationship between specific curriculum elements and students’ cross-disciplinary innovation competencies.

2.3 Theoretical Framework and Research Hypotheses

Based on the above literature review and the characteristics of the engineering-education intersection discipline, this study constructs a theoretical framework of the influence of blended curriculum model variables on students’ cross-disciplinary innovation competencies (Figure **??**), and puts forward corresponding research hypotheses. The framework includes six independent variables (curriculum elements), four dependent variables (sub-competencies of cross-disciplinary innovation competencies) and two moderating variables.

2.3.1 Core Independent Variables and Research Hypotheses

(1) Proportion of PBL in engineering courses: PBL is a student-centered teaching method that takes practical problems as the starting point and cultivates students' problem-solving ability and innovation ability [1]. In engineering courses of the engineering-education intersection discipline, PBL projects designed around educational application scenarios can help students connect engineering technology knowledge with educational needs, and improve their cross-disciplinary knowledge integration ability and educational problem engineering transformation ability. Therefore, this study proposes: H1: The proportion of PBL in engineering courses has a significant positive effect on students' cross-disciplinary innovation competencies.

(2) Number of educational technology integration practice courses: Educational technology integration practice courses are the core practical courses of the engineering-education intersection discipline, which focus on cultivating students' ability to apply engineering technology to solve educational practical problems [6]. More practice courses mean that students have more opportunities to carry out cross-disciplinary innovation practice, and their innovative design and development ability can be effectively improved. Therefore, this study proposes: H2: The number of educational technology integration practice courses has a significant positive effect on students' cross-disciplinary innovation competencies.

(3) Participation in industry-education collaborative innovation internships: Industry-education collaborative innovation internships refer to internships carried out by students in educational equipment enterprises, educational technology companies and other institutions, which can help students understand the actual needs of the industry and realize the transformation of classroom knowledge to practical application [14]. In internships, students need to collaborate with industry professionals and educational practitioners to complete innovation projects, which can comprehensively improve their cross-disciplinary innovation competencies. Therefore, this study proposes: H3: Participation in industry-education collaborative innovation internships has a significant positive effect on students' cross-disciplinary innovation competencies.

(4) Use of intelligent teaching evaluation tools: Intelligent teaching evaluation tools (such as learning analytics platforms, competency evaluation systems) can collect and analyze students' learning data in cross-disciplinary courses, provide personalized learning feedback, and help students find their own deficiencies in cross-disciplinary knowledge integration and practice [15]. This can optimize students' learning process and improve their cross-disciplinary innovation competencies. Therefore, this study proposes: H4: The use of intelligent teaching evaluation tools has a significant positive effect on students' cross-disciplinary innovation competencies.

2.3.2 Moderating Variables and Research Hypotheses

(1) Frequency of cross-disciplinary student team collaboration: Cross-disciplinary student team collaboration refers to the collaborative learning and project practice carried out by students from engineering, education and other majors [3]. In the process of collaboration, students can exchange knowledge and ideas between different disciplines, which can strengthen the effect of core curriculum variables on the cultivation of cross-disciplinary innovation competencies. Therefore, this study proposes: H5: The frequency of cross-disciplinary student team collaboration plays a significant positive moderating role in the influence of core curriculum variables (PBL proportion, practice courses, internships, intelligent tools) on students' cross-disciplinary innovation competencies.

(2) Implementation of engineering-education interdisciplinary team teaching: Interdisciplinary team teaching refers to the joint teaching carried out by teachers from engineering and education disciplines [9]. Teachers from different disciplines can provide students with comprehensive guidance on cross-disciplinary knowledge and practice, which can enhance the effectiveness of core curriculum variables. Therefore, this study proposes: H6: The implementation of engineering-education interdisciplinary team teaching plays a significant positive moderating role in the influence of core curriculum variables on students' cross-disciplinary innovation competencies.

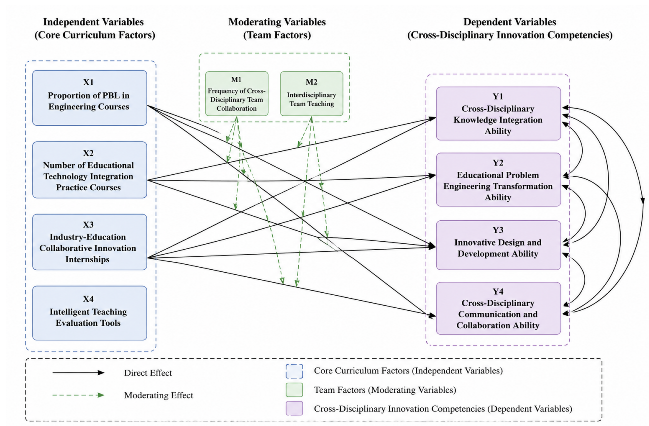

Figure 1. Theoretical Framework of the Influence of Blended Curriculum Model Variables on Cross-Disciplinary Innovation Competencies

3 Research Methods

3.1 Research Objects

This study selects three universities with typical engineering-education intersection programs as research objects, including University C (a research-oriented university in East China, China), University D (a comprehensive university in South

Korea) and University E (a technical university in the Netherlands). The three universities have different educational systems, cultural backgrounds and curriculum design characteristics, which can ensure the objectivity and universality of the research conclusions. University C's engineering-education intersection program is based on educational technology and electrical engineering, with a focus on industry-education collaboration with local educational equipment enterprises; University D's program integrates computer engineering and educational psychology, with a focus on project-based learning and online collaborative learning; University E's program is based on mechanical engineering and educational design, with a focus on intelligent teaching tools and international collaborative internships.

A total of 328 senior students who completed the engineering-education intersection program in the three universities were selected as research samples, including 126 from University C, 98 from University D and 104 from University E. All samples have completed all the courses and practical links of the program, and have certain cross-disciplinary learning and practice experience, which meets the research requirements.

3.2 Research Tools

3.2.1 Cross-Disciplinary Innovation Competencies Evaluation Scale

Based on the definition of cross-disciplinary innovation competencies in this study and the scale of Xu and Wu [14], this study compiles the Cross-Disciplinary Innovation Competencies Evaluation Scale for Engineering-Education Intersection Majors. The scale includes four dimensions: cross-disciplinary knowledge integration ability (6 items), educational problem engineering transformation ability (5 items), innovative design and development ability (6 items) and cross-disciplinary communication and collaboration ability (5 items), with a total of 22 items. The scale adopts a 5-point Likert scale, with scores from 1 (completely inconsistent) to 5 (completely consistent).

A pre-test was conducted on 60 students from the three universities, and the reliability and validity of the scale were tested. The results show that the Cronbach's α coefficient of the total scale is 0.912, and the Cronbach's α coefficients of each dimension are 0.856, 0.823, 0.878 and 0.845, all greater than 0.8, indicating high internal consistency reliability. The KMO value is 0.887, and the Bartlett spherical test is significant ($\chi^2 = 2156.34$, $p < 0.001$), indicating that the scale has good structural validity. The confirmatory factor analysis shows that the fitting indexes of the scale are $\chi^2/df = 2.36$, CFI=0.928, TLI=0.915, RMSEA=0.065, all meeting the fitting standards, indicating that the scale has good construct validity.

3.2.2 Blended Curriculum Model Variable Questionnaire

Based on the theoretical framework and research hypotheses, this study compiles the Blended Curriculum Model Variable Questionnaire for Engineering-Education Intersection Discipline, which measures six independent variables. The questionnaire includes: proportion of PBL in engineering courses (3 items), number of educational technology integration practice courses (2 items, measured by the actual number of courses completed by students), participation in industry-education collaborative innovation internships (3 items, dichotomous variable: 0=not participated, 1=participated), use of intelligent teaching evaluation tools (3 items), frequency of cross-disciplinary student team collaboration (3 items) and implementation of interdisciplinary team teaching (3 items). Except for the number of practice courses and internships, the other variables are measured by a 5-point Likert scale (1=never, 5=always). The pre-test results show that the Cronbach's α coefficient of the questionnaire is 0.876, with good reliability.

3.3 Data Collection and Processing

The research questionnaires were distributed to the research samples from January to March 2025 by means of online questionnaire and on-site distribution. A total of 350 questionnaires were distributed, and 328 valid questionnaires were recovered, with an effective recovery rate of 93.7%. The invalid questionnaires were excluded according to the following standards: questionnaires completed in less than 60 seconds, questionnaires with the same answers to all items, and questionnaires with missing key information.

SPSS 26.0 and AMOS 24.0 software were used for data processing and analysis. First, descriptive statistics and correlation analysis were conducted on all variables to understand the basic characteristics of the data and the correlation between variables; then, one-way ANOVA was used to compare the differences in students' cross-disciplinary innovation competencies under different blended curriculum models; finally, structural equation modeling (SEM) was used to test the research hypotheses, and the moderating effect was tested by the hierarchical regression method.

3.4 Research Design

This study adopts a mixed research method combining quantitative and qualitative research. The quantitative research is the main part, which uses one-way ANOVA and SEM to explore the influence of blended curriculum model variables on students' cross-disciplinary innovation competencies; the qualitative research is the supplementary part, which conducts semi-structured interviews with 15 curriculum designers and 30 students from the three universities to understand the actual implementation of the blended curriculum model and the problems in the cultivation of cross-disciplinary innovation competencies, so as to further explain and supplement the quantitative research results.

4 Research Results

4.1 Descriptive Statistics and Correlation Analysis

The descriptive statistics and correlation analysis results of all variables are shown in Table 1. The results show that the average score of students' cross-disciplinary innovation

Table 1. Descriptive Statistics and Correlation Analysis of Variables

Variable	M	SD	1	2	3	4	5	6	7
1. PBL proportion in engineering courses	3.65	0.78	1	-	-	-	-	-	-
2. Number of educational technology practice courses	4.21	1.05	0.368**	1	-	-	-	-	-
3. Industry-education collaborative internships	0.72	0.45	0.297**	0.312**	1	-	-	-	-
4. Intelligent teaching evaluation tools	3.42	0.86	0.389**	0.415**	0.301**	1	-	-	-
5. Cross-disciplinary team collaboration frequency	3.58	0.82	0.426**	0.458**	0.365**	0.402**	1	-	-
6. Interdisciplinary team teaching	3.36	0.91	0.398**	0.432**	0.328**	0.418**	0.526**	1	-
7. Cross-disciplinary innovation competencies	3.78	0.62	0.456**	0.512**	0.589**	0.396**	0.356**	0.289**	1

Note: ** $p < 0.01$, N=328; Variable 3 is a dichotomous variable (0=not participated, 1=participated).

competencies is 3.78 (SD=0.62), indicating that the overall level of cross-disciplinary innovation competencies of students majoring in engineering-education intersection is moderate to high. The correlation analysis results show that the four core independent variables (proportion of PBL in engineering courses, number of educational technology integration practice courses, industry-education collaborative innovation internships, intelligent teaching evaluation tools) are significantly positively correlated with cross-disciplinary innovation competencies (r=0.326–0.589, $p < 0.01$), and the two moderating variables (frequency of cross-disciplinary team collaboration, interdisciplinary team teaching) are also significantly positively correlated with cross-disciplinary innovation competencies (r=0.289–0.356, $p < 0.01$), which provides a preliminary basis for the subsequent hypothesis testing.

4.2 One-Way ANOVA of Cross-Disciplinary Innovation Competencies under Different Blended Curriculum Models

According to the combination characteristics of curriculum variables, the blended curriculum models of the three universities are divided into three types: Industry-Education Collaboration-Oriented Model (University C), PBL-Oriented Model (University D) and Intelligent Technology-Supported Model (University E). One-way ANOVA was used to compare the differences in students' cross-disciplinary innovation competencies under the three models, and the results are shown in Table 2.

The results show that there are significant differences in students' cross-disciplinary innovation competencies under different blended curriculum models (F=18.654, $p < 0.001$). The post-hoc comparison (LSD) results show that the average score of students' cross-disciplinary innovation competencies under the Industry-Education Collaboration-Oriented Model (M=4.12, SD=0.58) is significantly higher than that under the PBL-Oriented Model (M=3.75, SD=0.56, $p < 0.01$) and the Intelligent Technology-Supported Model (M=3.52, SD=0.61, $p < 0.001$); the average score under the PBL-Oriented Model is significantly higher than that under the Intelligent Technology-Supported Model ($p < 0.05$). This result indicates that the Industry-Education Collaboration-Oriented Model is the most effective in cultivating students' cross-disciplinary innovation competencies in the engineering-education intersection discipline.

4.3 Hypothesis Testing Based on Structural Equation Modeling

AMOS 24.0 software was used to construct a structural equation model to test the direct effects of the four core independent variables on students' cross-disciplinary innovation competencies (H1-H4). The fitting indexes of the model are $\chi^2/df = 2.18$, CFI=0.936, TLI=0.924, RMSEA=0.062, all meeting the ideal fitting standards, indicating that the model has a good fitting degree with the data.

The hypothesis testing results are shown in Table 3. The results show that: (1) The proportion of PBL in engineering courses has a significant positive effect on cross-disciplinary innovation competencies ($\beta = 0.278$, $p < 0.01$), so H1 is supported; (2) The number of educational technology integration practice courses has a significant positive effect on cross-disciplinary innovation competencies ($\beta = 0.389$, $p < 0.001$), so H2 is supported; (3) Industry-education collaborative innovation internships have the most significant positive effect on cross-disciplinary innovation competencies ($\beta = 0.426$, $p < 0.001$), so H3 is supported; (4) The use of intelligent teaching evaluation tools has a significant positive effect on cross-disciplinary innovation competencies ($\beta = 0.215$, $p < 0.05$), so H4 is supported.

4.4 Moderating Effect Testing

The hierarchical regression method was used to test the moderating effects of the frequency of cross-disciplinary student team collaboration and the implementation of interdisciplinary team teaching (H5-H6). Before the test, the centralization processing was carried out on all continuous variables to avoid the multicollinearity problem. The test results are shown in Table 4 and Table 5.

Table 4 shows the moderating effect test results of cross-disciplinary team collaboration frequency. The results show that the interaction terms of the four core independent variables and team collaboration frequency all have a significant positive effect on cross-disciplinary innovation competencies ($\beta = 0.126$–0.189, $p < 0.05$), indicating that the frequency of cross-disciplinary team collaboration plays a significant positive moderating role in the influence of core curriculum

Table 2. One-Way ANOVA of Cross-Disciplinary Innovation Competencies under Different Blended Curriculum Models

Curriculum Model	N	M	SD	F	p	Post-hoc Comparison
Industry-Education Collaboration-Oriented	126	4.12	0.58	18.654	0.000	1>2**; 1>3***; 2>3*
PBL-Oriented	98	3.75	0.56	-	-	-
Intelligent Technology-Supported	104	3.52	0.61	-	-	-

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; 1=Industry-Education Collaboration-Oriented Model, 2=PBL-Oriented Model, 3=Intelligent Technology-Supported Model.

Table 3. Direct Effect Hypothesis Testing Results

Hypothesis	Path	β	SE	CR	p	Result
H1	PBL proportion → competencies	0.278	0.089	3.124	0.002	Supported
H2	Practice courses → competencies	0.389	0.076	5.118	0.000	Supported
H3	Industry-education internships → competencies	0.426	0.082	5.195	0.000	Supported
H4	Intelligent tools → competencies	0.215	0.098	2.194	0.028	Supported

Table 4. Moderating Effect Test Results of Cross-Disciplinary Team Collaboration Frequency

Variable	Model 1	Model 2	Model 3
Control variables (gender, grade)	0.089	0.092	0.095
Core independent variables (PBL, practice courses, internships, intelligent tools)	0.586***	0.591***	0.602***
Team collaboration frequency	-	0.215**	0.228**
Interaction terms (core variables × team collaboration)	-	-	0.156**
R^2	0.343	0.389	0.426
ΔR^2	0.343***	0.046**	0.037**

Note: ***$p < 0.001$, *$p < 0.01$; The interaction terms are the cumulative effect of four interaction terms.

variables on cross-disciplinary innovation competencies, so H5 is supported.

Table 5 shows the moderating effect test results of interdisciplinary team teaching. The results show that the interaction terms of the four core independent variables and interdisciplinary team teaching all have a significant positive effect on cross-disciplinary innovation competencies ($\beta = 0.105$–0.156, $p < 0.05$), indicating that the implementation of interdisciplinary team teaching plays a significant positive moderating role in the influence of core curriculum variables on cross-disciplinary innovation competencies, so H6 is supported.

4.5 Qualitative Research Results

The semi-structured interview results show that the curriculum designers and students of the three universities all recognize the importance of industry-education collaborative internships and educational technology integration practice courses for the cultivation of cross-disciplinary innovation competencies. The curriculum designers of University C pointed out that "the industry-education collaborative internships let students understand the actual needs of the educational equipment industry, and the practice courses let students transform these needs into specific engineering design projects, which is the key to improving students' cross-disciplinary innovation ability". The students of University D said that "the PBL projects in engineering courses let us learn to connect engineering knowledge with educational problems, but the lack of industry practice makes it difficult for us to verify the practicality of our design works". The curriculum designers of University E mentioned that "intelligent teaching evaluation tools can effectively track students' learning process, but the lack of cross-disciplinary team collaboration makes it difficult for students to realize the integration of different disciplinary knowledge".

In addition, the interview results also found some problems in the current blended curriculum model of the engineering-education intersection discipline: (1) The connection between engineering courses and education courses is not close enough, and there is a phenomenon of "two separate lines"; (2) The number of industry-education collaborative internships is insufficient, and the quality of some internships is not high; (3) The level of interdisciplinary team teaching is uneven, and some teachers lack cross-disciplinary teaching

Table 5. Moderating Effect Test Results of Interdisciplinary Team Teaching

Variable	Model 1	Model 2	Model 3
Control variables (gender, grade)	0.089	0.091	0.093
Core independent variables (PBL, practice courses, internships, intelligent tools)	0.586***	0.590***	0.598***
Interdisciplinary team teaching	-	0.189**	0.196**
Interaction terms (core variables × team teaching)	-	-	0.128*
R^2	0.343	0.378	0.405
ΔR^2	0.343***	0.035**	0.027*

Note: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$; The interaction terms are the cumulative effect of four interaction terms.

ability; (4) The application of intelligent teaching evaluation tools is not in-depth enough, and it is mostly limited to the collection of learning data, lacking in-depth analysis and personalized feedback.

5 Discussion

5.1 Analysis of Core Variable Influence Results

The research results show that industry-education collaborative innovation internships have the most significant positive effect on students' cross-disciplinary innovation competencies in the engineering-education intersection discipline, which is consistent with the research conclusion of Xu and Wu [14] that off-campus internships have a significant effect on cross-disciplinary competencies. For the engineering-education intersection discipline, industry-education collaborative innovation internships are the key link connecting classroom teaching and industry practice. In internships, students are exposed to real educational application scenarios and industry needs, which can help them break the disciplinary barriers between engineering and education, and realize the integration of engineering technology knowledge and educational theory. At the same time, in the process of collaborating with industry professionals and educational practitioners, students' cross-disciplinary communication and collaboration ability and innovative design and development ability can be effectively improved. This fully shows that "practice is the source of innovation", and the cultivation of cross-disciplinary innovation competencies in the engineering-education intersection discipline must be closely combined with industry practice.

The number of educational technology integration practice courses has the second most significant positive effect on cross-disciplinary innovation competencies, which is in line with the research view of Gao et al. [6] that practical courses are the core of cross-disciplinary talent cultivation. Educational technology integration practice courses are the main carrier for students to carry out cross-disciplinary innovation practice. Through a large number of practice activities such as the design and development of educational equipment and the construction of intelligent teaching systems, students can continuously exercise their ability to apply engineering technology to solve educational practical problems, and their cross-disciplinary knowledge integration ability and educational problem engineering transformation ability can be continuously improved. The research results show that each additional educational technology integration practice course can significantly improve students' cross-disciplinary innovation competencies, which indicates that universities should increase the proportion of practical courses in the engineering-education intersection curriculum system and provide students with more cross-disciplinary innovation practice opportunities.

The proportion of PBL in engineering courses has a significant positive effect on cross-disciplinary innovation competencies, which verifies the research conclusion of Brassler and Dettmers [3] that PBL is an effective teaching method for cultivating cross-disciplinary competencies. In engineering courses of the engineering-education intersection discipline, PBL projects designed around educational application scenarios can make students take educational practical problems as the starting point, and actively learn and integrate engineering technology knowledge to solve these problems. This student-centered teaching method can effectively stimulate students' learning initiative and innovation consciousness, and improve their ability to analyze and solve cross-disciplinary problems. However, the influence intensity of PBL proportion is lower than that of internships and practice courses, which indicates that PBL needs to be combined with practical links to play a better role in the cultivation of cross-disciplinary innovation competencies.

The use of intelligent teaching evaluation tools has a significant positive effect on cross-disciplinary innovation competencies, which enriches the research on the influence of intelligent educational technology on cross-disciplinary talent cultivation [15]. Intelligent teaching evaluation tools can collect and analyze students' learning data in cross-disciplinary courses, such as the mastery of cross-disciplinary knowledge, the performance of practice projects and the effect of team collaboration, and provide personalized learning feedback for students. This can help students find their own deficiencies in cross-disciplinary learning and practice, and adjust their learning strategies in a timely manner, thus optimizing the learning process and improving cross-disciplinary innovation competencies. However, the influence intensity of intelligent teaching evaluation tools is the lowest among the four core variables, which is because the current application of intelligent teaching evaluation tools in the engineering-education intersection discipline is not in-depth enough, and most of them are limited to the collection and simple analysis of learning data, lacking in-depth mining and personalized guidance.

5.2 Analysis of Moderating Effect Results

The research results show that the frequency of cross-disciplinary student team collaboration and the implementation of interdisciplinary team teaching play significant positive moderating roles in the influence of core curriculum variables on cross-disciplinary innovation competencies, which is consistent with the research views of Pollard et al. [9] and Brassler and Dettmers [3]. Cross-disciplinary student team collaboration is an important way for students to exchange knowledge and ideas between different disciplines. In the process of collaborative learning and project practice, students from engineering, education and other majors can complement each other's advantages, share disciplinary knowledge and experience, and jointly solve cross-disciplinary problems. This can strengthen the effect of core curriculum variables such as PBL, practice courses and internships on the cultivation of cross-disciplinary innovation competencies, making the learning and practice process more effective.

Interdisciplinary team teaching is an important guarantee for the effective implementation of the blended curriculum model in the engineering-education intersection discipline. Teachers from engineering and education disciplines have different professional backgrounds and teaching experiences, and joint teaching can provide students with comprehensive guidance on cross-disciplinary knowledge, practice and innovation. Engineering teachers can guide students in engineering technology design and development, and education teachers can guide students in educational scenario analysis and teaching design. This complementary teaching can help students better integrate engineering technology and educational theory, and enhance the effectiveness of core curriculum variables on the cultivation of cross-disciplinary innovation competencies. However, the moderating effect intensity of interdisciplinary team teaching is lower than that of cross-disciplinary team collaboration, which is because the current interdisciplinary team teaching in many universities is still in the preliminary stage, and there are problems such as insufficient communication and cooperation between teachers, inconsistent teaching goals and lack of unified teaching evaluation standards.

5.3 Comparison of Different Blended Curriculum Models

The one-way ANOVA results show that the Industry-Education Collaboration-Oriented Model is the most effective in cultivating students' cross-disciplinary innovation competencies, followed by the PBL-Oriented Model and the Intelligent Technology-Supported Model. This result is closely related to the curriculum design characteristics of the three models: the Industry-Education Collaboration-Oriented Model takes industry-education collaborative innovation internships as the core, and matches with a large number of educational technology integration practice courses and a certain proportion of PBL, forming a "practice-driven" curriculum system, which is highly consistent with the talent cultivation needs of the engineering-education intersection discipline; the PBL-Oriented Model takes PBL as the main teaching method, but the lack of sufficient industry practice links makes it difficult for students to verify the practicality of their innovation results; the Intelligent Technology-Supported Model focuses on the application of intelligent teaching evaluation tools, but the lack of close connection between engineering and education courses and insufficient cross-disciplinary practice opportunities limit the improvement of students' cross-disciplinary innovation competencies.

This comparison result shows that the design of the blended curriculum model for the engineering-education intersection discipline must take "industry-education collaboration and practical application" as the core, and organically integrate various curriculum elements around this core. Simply emphasizing a single curriculum element (such as PBL or intelligent technology) cannot effectively cultivate students' cross-disciplinary innovation competencies. Only by forming a systematic and integrated blended curriculum model that combines "theoretical teaching, practical training and industry practice" can we comprehensively improve students' cross-disciplinary innovation competencies.

5.4 Practical Implications

Based on the above research results, this study puts forward the following practical implications for the design and implementation of the blended curriculum model in the engineering-education intersection discipline:

First, take industry-education collaborative innovation internships as the core, and build a "practice-driven" curriculum system. Universities should strengthen cooperation with educational equipment enterprises, educational technology companies and other institutions, build a stable industry-education collaborative practice base, increase the number of industry-education collaborative innovation internships, and improve the quality of internships. The internship content should be closely combined with the talent cultivation goals of the engineering-education intersection discipline, focusing on cultivating students' ability to solve actual industrial problems with cross-disciplinary knowledge. At the same time, universities should assign special tutors to track and guide students' internship process, and establish a scientific internship evaluation system to ensure the effectiveness of internships.

Second, increase the number of educational technology integration practice courses, and build a hierarchical practical training system. Universities should design a hierarchical practical training system including basic practice, professional practice and innovative practice according to the cognitive law of students. Basic practice courses focus on cultivating students' basic engineering skills and educational theory application ability; professional practice courses focus on cultivating students' ability to integrate engineering technology and educational theory to solve professional problems; innovative practice courses focus on cultivating students' cross-disciplinary innovation design and development ability. The practical training content should be closely combined with the latest development of the industry, and introduce the latest educational technology and engineering equipment to ensure the timeliness and practicality of the practical training content.

Third, optimize the proportion of PBL in engineering courses, and design PBL projects combined with educational application scenarios. Universities should increase the proportion of PBL in engineering courses of the engineering-education intersection discipline, and design PBL projects around real educational application scenarios such as the research and development of intelligent teaching equipment, the construction of online education platforms and the design of engineering education courses. In the process of PBL implementation, students should be organized to form cross-disciplinary teams to carry out collaborative learning and project practice, and teachers from engineering and education disciplines should be invited to provide joint guidance to students.

Fourth, deepen the application of intelligent teaching evaluation tools, and build a "technology-supported" learning evaluation system. Universities should introduce advanced intelligent teaching evaluation tools such as learning analytics platforms and competency evaluation systems, collect and analyze students' learning data in cross-disciplinary courses and practice links in an all-round way, and provide personalized learning feedback and guidance for students. At the same time, universities should strengthen the training of teachers' intelligent teaching technology application ability, and guide teachers to use intelligent teaching evaluation tools to optimize the teaching process and improve the teaching effect.

Fifth, strengthen cross-disciplinary team collaboration and interdisciplinary team teaching, and build a "collaborative development" teaching and learning environment. Universities should organize students from engineering, education and other majors to form cross-disciplinary teams to carry out collaborative learning and project practice in various courses and practical links, and establish a scientific team collaboration evaluation system to encourage students to carry out cross-disciplinary communication and cooperation. At the same time, universities should build an interdisciplinary teaching team composed of engineering and education teachers, strengthen the communication and cooperation between teachers, unify teaching goals and evaluation standards, and improve the level of interdisciplinary team teaching.

6 Conclusions and Limitations

6.1 Research Conclusions

This study takes the engineering-education intersection discipline as the research perspective, takes three universities with different educational systems and cultural backgrounds as research objects, and uses a mixed research method combining one-way ANOVA and structural equation modeling to explore the key variables affecting students' cross-disciplinary innovation competencies and the effectiveness of different blended curriculum models. The main research conclusions are as follows:

Six variables of the blended curriculum model in the engineering-education intersection discipline are closely related to students' cross-disciplinary innovation competencies, including four core independent variables (proportion of PBL in engineering courses, number of educational technology integration practice courses, industry-education collaborative innovation internships, use of intelligent teaching evaluation tools) and two moderating variables (frequency of cross-disciplinary student team collaboration, implementation of engineering-education interdisciplinary team teaching).

The four core independent variables all have significant positive effects on students' cross-disciplinary innovation competencies, and the influence intensity from high to low is: industry-education collaborative innovation internships ($\beta = 0.426$, $p < 0.001$) $>$ educational technology integration practice courses ($\beta = 0.389$, $p < 0.001$) $>$ proportion of PBL in engineering courses ($\beta = 0.278$, $p < 0.01$) $>$ intelligent teaching evaluation tools ($\beta = 0.215$, $p < 0.05$).

The two moderating variables both play significant positive moderating roles in the influence of core curriculum variables on cross-disciplinary innovation competencies, that is, the higher the frequency of cross-disciplinary student team collaboration and the better the implementation of interdisciplinary team teaching, the more significant the positive effect of core curriculum variables on cross-disciplinary innovation competencies.

There are significant differences in students' cross-disciplinary innovation competencies under different blended curriculum models, and the Industry-Education Collaboration-Oriented Model is the most effective in cultivating students' cross-disciplinary innovation competencies, followed by the PBL-Oriented Model and the Intelligent Technology-Supported Model.

Based on the above research results, this study constructs a "practice-driven, technology-supported" blended curriculum design framework for the engineering-education intersection discipline, which takes industry-education collaborative innovation internships as the core, takes educational technology integration practice courses and PBL as the main body, takes intelligent teaching evaluation tools as the support, and takes cross-disciplinary team collaboration and interdisciplinary team teaching as the guarantee.

6.2 Research Limitations and Future Research Directions

This study still has some limitations: First, the research objects are only three universities in East Asia and Europe, and the sample size is relatively limited, which may affect the universality of the research conclusions; Second, the research adopts a cross-sectional research design, which can only reveal the correlation between variables, and cannot fully reveal the dynamic development process of the influence of curriculum variables on students' cross-disciplinary innovation competencies; Third, the research focuses on the quantitative analysis of curriculum variables, and the in-depth exploration of the internal psychological mechanism of students' cross-disciplinary innovation competencies cultivation is insufficient.

In view of the above limitations, the future research directions are as follows: First, expand the research sample, select more universities in different countries and regions with engineering-education intersection programs as research objects, and verify the research conclusions to improve their universality; Second, adopt a longitudinal research design, track the learning and development process of students majoring in engineering-education intersection for a long time, and explore the dynamic influence path of curriculum variables on students' cross-disciplinary innovation competencies; Third, combine quantitative research with qualitative research, use methods such as grounded theory and case study to explore the internal psychological mechanism of students' cross-disciplinary innovation competencies cultivation, such as the role of learning motivation, cross-disciplinary thinking and self-efficacy; Fourth, explore the optimization strategy of the blended curriculum model in the engineering-education intersection discipline under the background of digital transformation, and study the application of emerging technologies such as artificial intelligence and big data in the cultivation of cross-disciplinary innovation competencies.

Acknowledgements

This study was supported by the National Social Science Fund of China (Education Science) Project "Research on the Cultivation of Cross-Disciplinary Innovation Competencies of Students Majoring in Engineering-Education Intersection" (Project No.: EIA240456). The authors would like to thank the curriculum designers and students of the three universities for their support and cooperation in the questionnaire survey and interview. The authors also thank the anonymous reviewers for their valuable comments and suggestions on this paper.

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