

# Measuring the Effect of Interdisciplinary Learning Factory Projects on Student Learning Outcomes

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## ABSTRACT

The rapid development of interdisciplinary knowledge and industry-driven education models has encouraged higher education institutions to adopt more experiential and collaborative learning approaches. **The growing demand** for graduates who possess not only theoretical knowledge but also practical competencies, collaborative abilities, and innovation skills has driven universities to integrate real-world project environments into the learning process through Learning Factory models. **This study aims** to measure the effect of interdisciplinary Learning Factory projects on student learning outcomes in higher education environments. **The research applies** a quantitative approach using a survey-based method involving students who participated in interdisciplinary Learning Factory projects, with the collected data analyzed through statistical analysis techniques to examine the relationship between interdisciplinary project activities and learning outcomes. **The findings reveal** that interdisciplinary Learning Factory projects significantly improve student learning outcomes, particularly in the areas of problem-solving ability, critical thinking, collaboration, and the integration of theoretical and practical knowledge. Students who participate in interdisciplinary projects demonstrate higher engagement and stronger capability to address complex real-world problems compared to those involved in traditional learning environments. **These findings suggest** that the integration of interdisciplinary Learning Factory projects provides an effective learning strategy for enhancing student competencies and supporting the development of practical, collaborative, and innovation-oriented skills required in modern educational and industrial contexts.

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## 1. INTRODUCTION

The rapid advancement of digital technologies, automation, artificial intelligence, and global connectivity has significantly transformed the landscape of higher education and the competencies expected from university graduates [1]. In the era of Industry 4.0 and the emerging paradigm of Industry 5.0, organizations increasingly demand graduates who possess not only strong theoretical knowledge but also the ability to apply interdisciplinary skills to address complex and dynamic problems [2]. The modern workforce requires individuals who are capable of critical thinking, creative problem-solving, collaboration, adaptability, and continuous

learning. However, traditional lecture-based learning approaches that emphasize passive knowledge transfer often fail to fully prepare students for these evolving professional demands. Consequently, universities around the world are increasingly shifting toward more experiential, collaborative, and practice-oriented learning models that emphasize real-world engagement and interdisciplinary interaction [3]. One educational approach that has gained substantial attention in recent years is the Learning Factory model, which integrates elements of industrial practice into the academic learning environment. The Learning Factory concept provides students with opportunities to engage directly with real-world problems, simulate industrial processes, and collaborate on multidisciplinary projects that mirror professional practices [4]. Through this model, students can experience authentic learning situations that connect theoretical knowledge with practical applications, enabling them to develop deeper understanding and stronger competencies relevant to modern industrial environments.

Alongside the transformation of learning models, interdisciplinary education has emerged as a crucial component of modern higher education systems. Contemporary societal and technological challenges rarely belong to a single field of knowledge. Instead, they require the integration of multiple disciplines to develop effective and innovative solutions [5]. For instance, challenges related to smart manufacturing, digital transformation, sustainable development, and technological innovation require collaboration between engineers, designers, data analysts, business experts, and social scientists. As a result, universities are increasingly encouraged to design learning environments that promote interdisciplinary collaboration among students from different academic backgrounds [6]. Interdisciplinary project-based learning provides students with opportunities to combine diverse knowledge perspectives, exchange ideas, and develop holistic approaches to complex problems. Within such learning environments, students not only acquire technical knowledge from their own discipline but also learn how to communicate and collaborate with peers who possess different expertise [7]. This process helps cultivate integrative thinking, creativity, and innovation capabilities. In this context, interdisciplinary Learning Factory projects offer a powerful platform where students can engage in collaborative problem-solving activities while experiencing real-world industrial challenges. These projects encourage students to apply knowledge from multiple disciplines simultaneously, thereby enhancing both their intellectual development and their readiness for professional work environments [8].

The Learning Factory concept itself originated from initiatives aimed at reducing the gap between academic education and industrial practice. Traditionally, many graduates experience difficulties when transitioning from university learning environments to professional workplaces because of the differences between theoretical instruction and practical application [9]. Learning Factory environments seek to address this issue by creating educational settings that replicate real industrial systems, including production processes, technological tools, collaborative workflows, and problem-solving scenarios [10]. In such environments, students actively participate in project-based learning activities that involve designing solutions, developing prototypes, analyzing systems, and implementing improvements within simulated or real industrial contexts. The Learning Factory approach often incorporates elements such as experiential learning, collaborative teamwork, digital technology integration, and industry partnerships [11]. Through these components, students are encouraged to engage in active learning processes where knowledge is constructed through experience and reflection. Numerous educational studies have indicated that hands-on learning environments such as Learning Factories can significantly increase student engagement, motivation, and practical competence [12]. Students participating in Learning Factory projects tend to demonstrate stronger problem-solving abilities, improved analytical thinking, and greater confidence in applying theoretical concepts to practical situations. Furthermore, by incorporating interdisciplinary collaboration into these environments, Learning Factory projects can provide even richer learning experiences that more accurately reflect the complexities of modern industrial ecosystems [13].

Despite the growing popularity of Learning Factory implementations in higher education institutions across different countries, there remains a need for more systematic empirical research that evaluates their effectiveness in improving student learning outcomes [14]. Many universities have adopted Learning Factory models as part of their curriculum innovation strategies. However, the measurement of educational outcomes associated with these initiatives is still relatively limited. In particular, the impact of interdisciplinary Learning Factory projects on student learning outcomes requires deeper investigation [15]. Student learning outcomes in higher education are typically understood as measurable indicators of knowledge acquisition, skill development, and competency growth that occur during the learning process. These outcomes may include cognitive competencies such as critical thinking and analytical reasoning, as well as practical competencies such as problem-solving ability, teamwork, and the capacity to integrate theoretical knowledge with real-world applications [16]. Evaluating these outcomes is essential for determining whether innovative learning models such

as Learning Factories truly contribute to educational improvement. Quantitative research methods provide valuable tools for measuring these relationships in a systematic and objective manner [17]. By collecting data from students who have participated in interdisciplinary Learning Factory projects and analyzing these data using statistical techniques, researchers can identify patterns and relationships that reveal how such learning experiences influence student performance and competency development. Such empirical evidence is important for guiding curriculum development, informing educational policy, and supporting the broader adoption of effective experiential learning models in higher education [18].

Based on the considerations above, this study aims to measure the effect of interdisciplinary Learning Factory projects on student learning outcomes within a higher education environment [19]. Specifically, the research focuses on examining how participation in interdisciplinary project-based activities within a Learning Factory framework influences students' learning achievements, engagement levels, and competency development. The study employs a quantitative research approach in which data are collected from students who have been involved in interdisciplinary Learning Factory projects [20]. The collected data are analyzed using statistical analysis techniques to explore the relationships between interdisciplinary collaboration, experiential project participation, and measurable learning outcomes. The results of this study are expected to provide empirical insights into the effectiveness of interdisciplinary Learning Factory models in enhancing student learning experiences [21]. In addition, the findings may contribute to the ongoing development of innovative educational strategies that integrate practical experience with academic learning. For universities seeking to strengthen the relevance of their curricula to industry needs, understanding the impact of interdisciplinary Learning Factory projects can provide valuable guidance for designing more effective project-based learning environments [22]. Ultimately, by promoting experiential learning, interdisciplinary collaboration, and real-world problem-solving, Learning Factory projects have the potential to significantly improve the quality of higher education and better prepare students to meet the challenges of rapidly evolving industrial and technological landscapes [23].

## 2. LITERATURE REVIEW

### 2.1. Learning Factory in Higher Education

The Learning Factory concept has become an increasingly important educational model in higher education, particularly in engineering, technology, manufacturing, and applied sciences [24]. This educational approach was developed to address the gap between theoretical learning in academic institutions and the practical competencies required in industrial environments. Traditional higher education systems often emphasize theoretical instruction through lecture-based learning approaches, which may limit students' opportunities to apply knowledge in realistic contexts [25]. As industries continue to evolve under the influence of digital transformation, automation, and Industry 4.0 technologies, universities are increasingly expected to prepare graduates who possess not only conceptual understanding but also practical skills, collaborative abilities, and problem-solving competencies. In response to these demands, Learning Factory environments have emerged as innovative learning platforms that integrate experiential learning, industrial simulation, and project-based activities into academic curricula [26].

Learning Factory environments provide students with opportunities to experience authentic industrial processes through hands-on learning activities, collaborative teamwork, and real-world problem-solving situations [27]. Within these environments, students are encouraged to actively participate in designing solutions, analyzing production systems, implementing technological tools, and evaluating operational performance. Such activities allow students to bridge the gap between theory and practice while simultaneously developing competencies relevant to professional and industrial contexts [28]. Furthermore, Learning Factory implementation encourages students to become more engaged in the learning process because they are directly involved in practical activities that simulate actual workplace environments. This active learning process supports deeper conceptual understanding and enhances students' ability to apply academic knowledge in solving practical and interdisciplinary challenges [29].

In recent years, the role of Learning Factories has expanded beyond technical training and production simulation. Modern Learning Factory systems increasingly emphasize interdisciplinary collaboration, innovation development, and digital competency integration [30]. Students from different academic disciplines are often required to collaborate in solving complex industrial problems, reflecting the multidisciplinary nature of contemporary industries. Through interdisciplinary project activities, students develop communication skills,

teamwork effectiveness, adaptability, and knowledge integration capabilities that are essential for Industry 4.0 and Industry 5.0 environments [31]. As a result, Learning Factory implementation is increasingly recognized as an effective educational strategy for improving student learning outcomes and strengthening graduate readiness for dynamic industrial and technological landscapes.

## 2.2. Interdisciplinary Learning in Higher Education

Interdisciplinary learning has emerged as an important educational strategy in response to the increasing complexity of societal, technological, and industrial challenges in the modern era. Many contemporary problems cannot be effectively solved through a single disciplinary perspective because they involve interconnected technical, social, organizational, and technological dimensions [32]. Consequently, higher education institutions are increasingly encouraged to create learning environments that promote interdisciplinary collaboration and knowledge integration among students from different academic backgrounds. Interdisciplinary learning allows students to combine perspectives from multiple fields of study, enabling them to develop broader analytical understanding and more comprehensive problem-solving approaches [33].

In higher education contexts, interdisciplinary learning environments encourage students to collaborate on shared projects, exchange knowledge, and integrate different forms of expertise to achieve common objectives. Through this collaborative process, students are exposed to diverse perspectives and alternative methods for addressing complex problems [34]. These experiences contribute to the development of critical thinking, creativity, communication ability, and teamwork effectiveness. Furthermore, interdisciplinary collaboration encourages students to become more adaptable and open-minded because they are required to interact with peers who possess different academic perspectives and problem-solving approaches. Such competencies are increasingly important in modern industries where multidisciplinary teamwork and collaborative innovation are essential for organizational success [35].

The integration of interdisciplinary learning within Learning Factory environments provides additional educational advantages because students are not only exposed to collaborative knowledge exchange but also required to apply interdisciplinary concepts in practical and industrial contexts [36]. Learning Factory projects often involve real-world industrial simulations that require students to combine technical knowledge, managerial understanding, analytical reasoning, and communication skills simultaneously. As students participate in interdisciplinary project-based activities, they develop the ability to integrate theoretical concepts from multiple disciplines while solving practical industrial challenges. Therefore, interdisciplinary Learning Factory implementation represents a highly relevant educational approach for preparing graduates who are capable of addressing the complex and rapidly evolving demands of Industry 4.0 and Industry 5.0 environments [37].

## 2.3. Project-Based Learning and Experiential Education

Project-Based Learning is widely recognized as one of the most effective educational approaches for promoting active and meaningful learning experiences in higher education [38]. Unlike traditional lecture-centered instruction, project-based learning emphasizes student participation in practical projects that require investigation, collaboration, critical thinking, and problem-solving activities. Through project-based learning environments, students are encouraged to explore real-world challenges, analyze problems systematically, and develop practical solutions through collaborative teamwork [39]. This learning approach supports the development of both cognitive and practical competencies because students actively construct knowledge through direct engagement with learning activities rather than passively receiving information from instructors.

Experiential education, which forms the theoretical foundation of project-based learning, emphasizes learning through direct experience, reflection, and active participation [40]. According to experiential learning principles, students develop deeper understanding when they are directly involved in authentic learning situations that require practical application of theoretical knowledge. Learning Factory environments strongly reflect experiential learning characteristics because students participate in hands-on industrial simulations, collaborative projects, and practical problem-solving activities [41]. These experiences allow students to connect theoretical concepts with practical implementation while simultaneously developing professional competencies such as teamwork, communication, adaptability, and decision-making ability.

Furthermore, project-based and experiential learning environments significantly contribute to student motivation and engagement because students become more actively involved in the educational process. Students participating in experiential learning activities often demonstrate higher levels of enthusiasm, responsibility, and commitment toward learning tasks because they perceive the activities as relevant to real-world professional situations [42]. In interdisciplinary Learning Factory environments, project-based activities also

encourage students to collaborate with peers from different academic disciplines, allowing them to develop broader perspectives and stronger interpersonal competencies. As a result, project-based experiential learning is increasingly viewed as an effective educational strategy for improving student learning outcomes and preparing graduates for complex industrial and organizational environments [43].

#### 2.4. Student Learning Outcomes in Experiential Learning Environments

Student learning outcomes represent measurable indicators of the knowledge, competencies, skills, and educational achievements acquired during the learning process [44]. In modern higher education systems, learning outcomes are not only evaluated through academic performance indicators such as examination scores and course grades but also through the development of practical competencies, interpersonal skills, and problem-solving abilities. Educational institutions increasingly recognize that successful graduates must possess competencies that extend beyond theoretical understanding, including communication ability, collaboration effectiveness, adaptability, creativity, and the capacity to apply knowledge in practical situations [45]. Consequently, evaluating student learning outcomes has become an essential component of educational research and curriculum development.

Experiential learning environments such as Learning Factories provide opportunities for students to acquire both cognitive and practical competencies simultaneously [46]. Through hands-on project activities, interdisciplinary collaboration, and industrial simulations, students develop deeper understanding of theoretical concepts while gaining practical experience in solving real-world problems [47]. Research in experiential education consistently indicates that students who participate in active learning environments demonstrate stronger engagement, higher motivation, and improved analytical thinking compared to those who primarily experience traditional classroom instruction. These learning environments encourage students to become active participants in knowledge construction processes, which contributes to more meaningful and sustainable learning experiences [48].

In addition, experiential learning activities support the development of higher-order thinking skills such as critical thinking, evaluation, synthesis, and innovation. Students involved in interdisciplinary Learning Factory projects are required to analyze practical problems, evaluate alternative solutions, integrate knowledge from multiple disciplines, and collaborate effectively within multidisciplinary teams [49]. These experiences help students strengthen their problem-solving abilities and prepare them for increasingly complex industrial and professional environments. Therefore, student learning outcomes within experiential learning environments should be understood as multidimensional constructs that include cognitive development, practical competency acquisition, interpersonal skill improvement, and professional readiness [50].

#### 2.5. Interdisciplinary Collaboration and Innovation Skills

Innovation skills are increasingly recognized as critical competencies required in modern industrial and technological environments. Rapid technological development, digital transformation, and global industrial competition require organizations to employ individuals who are capable of thinking creatively, collaborating effectively, and adapting to complex changes [51]. Higher education institutions therefore play an important role in developing innovation-oriented competencies among students through collaborative and experiential learning approaches. One educational strategy that strongly supports innovation development is interdisciplinary collaboration because it enables students to combine knowledge, perspectives, and problem-solving approaches from different academic disciplines [52].

Interdisciplinary collaboration encourages students to engage in collective problem-solving activities that require communication, teamwork, negotiation, and knowledge integration. Students working within interdisciplinary project teams are exposed to alternative viewpoints and analytical frameworks that stimulate creativity and innovative thinking [53]. Through interaction with peers from different academic backgrounds, students learn how to evaluate problems from broader perspectives and develop more comprehensive solutions. These collaborative experiences contribute significantly to the development of adaptability, communication ability, and innovation-oriented competencies that are increasingly important in Industry 4.0 and Industry 5.0 environments.

Learning Factory environments provide highly suitable platforms for interdisciplinary collaboration because students are required to solve practical industrial problems within simulated real-world settings. In such environments, innovation emerges through collaborative interaction, experimentation, and practical application of interdisciplinary knowledge [54]. Students not only develop technical competencies but also learn how to collaborate effectively, manage project responsibilities, and integrate multiple forms of expertise to

achieve shared objectives. Therefore, interdisciplinary collaboration within Learning Factory systems contributes significantly to preparing graduates who are capable of responding to modern industrial challenges through creative, adaptive, and collaborative approaches.

## 2.6. Research Gap and Conceptual Foundation

Previous studies have emphasized the importance of innovative and industry-oriented educational approaches in improving student competencies and preparing graduates for future professional challenges. The integration of interdisciplinary learning, experiential activities, and project-based educational models has been recognized as an effective strategy for enhancing students' practical understanding, collaboration skills, and adaptability within modern educational environments [55]. In addition, project-based learning approaches have been shown to support the development of critical thinking, communication ability, and active student engagement throughout the learning process [56].

However, despite the growing implementation of interdisciplinary and experiential learning approaches in higher education, limited studies have specifically examined the measurable effect of interdisciplinary Learning Factory projects on broader student learning outcomes. Existing research has largely focused on pedagogical innovation and project-based instructional strategies without comprehensively investigating how collaboration, experiential learning, and knowledge integration within Learning Factory environments contribute to students' cognitive development, problem-solving ability, collaboration competence, and practical knowledge application. As a result, empirical understanding regarding the educational impact of interdisciplinary Learning Factory implementation on student learning outcomes remains relatively limited [57].

Therefore, this study seeks to address the identified research gap by examining the effect of interdisciplinary Learning Factory projects on student learning outcomes using a quantitative research approach. The study focuses on how collaborative activities, experiential learning processes, and interdisciplinary knowledge integration within Learning Factory environments contribute to improving students' competencies and professional readiness in higher education contexts. Based on these relationships, a conceptual framework is proposed to illustrate the connection between interdisciplinary Learning Factory activities and student learning outcomes, as presented in Figure 1.

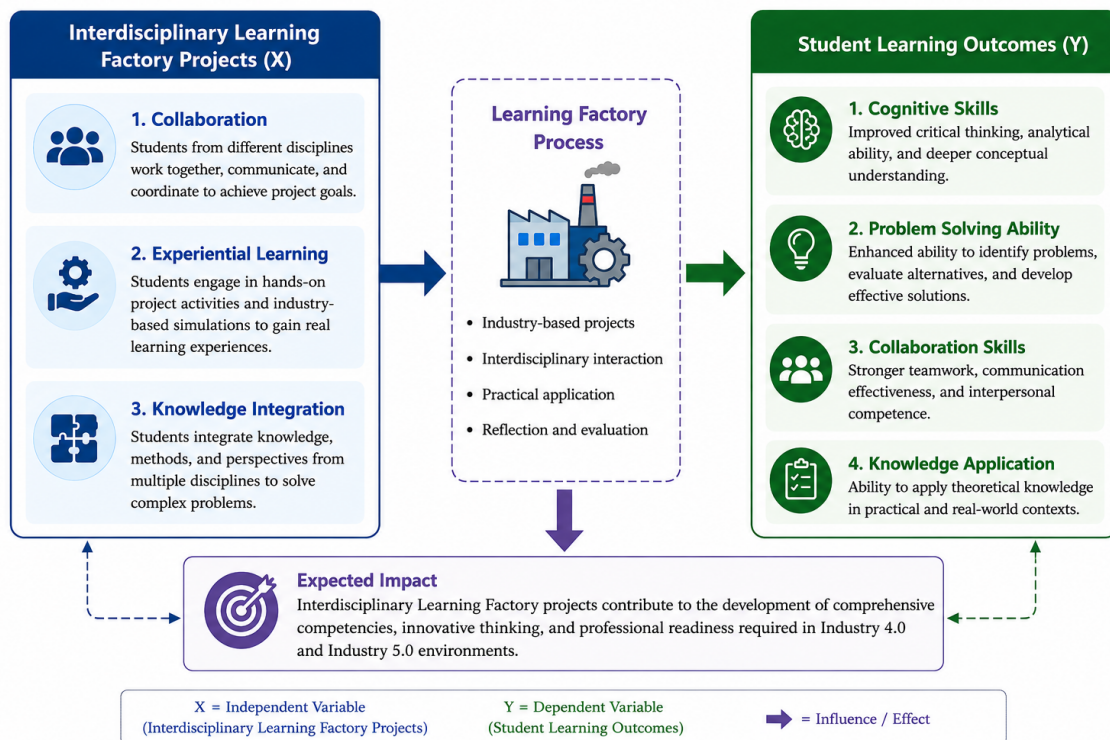


Figure 1. Conceptual Framework of Interdisciplinary Learning Factory Projects and Student Learning Outcomes

Figure 1 illustrates the conceptual relationship between interdisciplinary Learning Factory projects and student learning outcomes examined in this study. The framework demonstrates that collaboration, experiential learning, and knowledge integration within Learning Factory environments function as important educational mechanisms that influence students' cognitive skills, problem-solving ability, collaboration competence, and practical knowledge application. As presented in Figure 1, interdisciplinary Learning Factory activities are expected to create meaningful experiential learning experiences that support competency development and professional readiness among students in higher education environments.

### 3. RESEARCH METHODOLOGY

#### 3.1. Research Design

This study employed a quantitative research design to examine the effect of interdisciplinary Learning Factory projects on student learning outcomes in higher education environments. A quantitative approach was considered appropriate because the study aimed to measure the relationship between interdisciplinary Learning Factory implementation and various dimensions of student competency development using numerical data and statistical analysis techniques. The research focused on identifying how collaboration, experiential learning activities, and interdisciplinary knowledge integration within Learning Factory environments contribute to improving students' cognitive skills, problem-solving ability, collaboration competence, and practical knowledge application. Through this approach, the study sought to provide empirical evidence regarding the educational effectiveness of interdisciplinary Learning Factory implementation in supporting competency development and professional readiness among students.

The research applied a survey-based design in which data were collected through structured questionnaires distributed to students who had participated in interdisciplinary Learning Factory activities. The questionnaire was designed using a Likert scale to measure students' perceptions and experiences related to collaborative learning, experiential project activities, knowledge integration processes, and learning outcomes achieved during Learning Factory implementation. The collected data were then analyzed quantitatively to evaluate the relationship between the independent variable, namely interdisciplinary Learning Factory projects, and the dependent variable, namely student learning outcomes. In addition, validity and reliability testing procedures were conducted to ensure the consistency, accuracy, and credibility of the research instrument before further statistical analysis was performed.

To support a more systematic analysis, this study also utilized statistical methods to examine the influence of interdisciplinary Learning Factory implementation on student learning outcomes. The analysis process included descriptive statistical analysis to identify respondent characteristics and overall response tendencies, followed by inferential statistical analysis to evaluate the significance of the relationship between research variables. Through this research design, the study was expected to generate objective and measurable findings regarding the contribution of interdisciplinary Learning Factory activities to improving student competencies, engagement, collaboration effectiveness, and professional preparedness within higher education contexts aligned with the demands of Industry 4.0 and Industry 5.0 environments.

#### 3.2. Research Variables and Indicators

This study involves two primary variables, namely Interdisciplinary Learning Factory Projects (X) as the independent variable and Student Learning Outcomes (Y) as the dependent variable. The independent variable represents collaborative and experiential learning activities implemented through interdisciplinary Learning Factory projects. These activities emphasize practical engagement, interdisciplinary teamwork, knowledge integration, and problem-solving within simulated industrial environments.

Meanwhile, student learning outcomes represent the competencies and educational achievements acquired by students after participating in Learning Factory activities. The learning outcomes examined in this study include cognitive competencies, collaboration skills, practical problem-solving ability, and the capability to apply theoretical knowledge to real-world situations. These competencies are considered essential indicators of successful experiential learning implementation in higher education.

To operationalize the variables, each variable is divided into several measurable dimensions and indicators. The indicators were developed based on previous studies related to experiential learning, interdisciplinary collaboration, project-based learning, and student competency development. All indicators are measured using a structured questionnaire based on a five-point Likert scale ranging from strongly disagree to strongly agree.

Table 1. Research Variables and Indicators

Variable	Dimension	Indicators
Interdisciplinary Learning Factory Project (X)	Collaboration	Interdisciplinary teamwork and communication
	Experiential Learning	Hands-on project activities and real-world problem solving
	Knowledge Integration	Ability to integrate knowledge from multiple disciplines
Student Learning Outcomes (Y)	Cognitive Skills	Critical thinking and analytical ability
	Problem Solving	Ability to identify and solve complex problems
	Collaboration Skills	Teamwork effectiveness and communication
	Knowledge Application	Applying theoretical concepts to practical tasks

Table 1 presents the research variables and indicators used in this study. The interdisciplinary Learning Factory project variable focuses on collaborative and experiential learning dimensions that reflect authentic industrial learning environments. Meanwhile, the student learning outcomes variable emphasizes competency development related to critical thinking, problem-solving, teamwork, and knowledge application. These indicators serve as the basis for constructing the questionnaire instrument and conducting quantitative analysis.

### 3.3. Population and Sample

The population of this study consisted of university students who had participated in interdisciplinary Learning Factory activities within higher education environments. These students were selected as the research population because they had direct experience with collaborative project-based learning, experiential industrial simulation activities, and interdisciplinary knowledge integration processes implemented within Learning Factory environments. The population was considered relevant to the objectives of the study because the research specifically focused on examining the effect of interdisciplinary Learning Factory projects on student learning outcomes, including cognitive skills, problem-solving ability, collaboration competence, and practical knowledge application.

This study applied a purposive sampling technique to select respondents who met specific research criteria. The sampling approach was considered appropriate because not all students had experience participating in interdisciplinary Learning Factory activities. Therefore, the respondents included in this study were students who had actively participated in collaborative Learning Factory projects involving interdisciplinary teamwork, practical project activities, and experiential learning processes. By selecting respondents with direct involvement in Learning Factory implementation, the study aimed to obtain more accurate and relevant data regarding students' perceptions and experiences related to interdisciplinary collaboration and competency development within Learning Factory environments.

The sample size was determined based on the availability of respondents who fulfilled the established research criteria and were willing to participate in the study. Data were collected through questionnaire distribution to selected respondents in order to obtain quantitative information regarding the relationship between interdisciplinary Learning Factory implementation and student learning outcomes. Through the use of purposive sampling and respondent selection based on specific participation criteria, the study was expected to generate representative and reliable findings concerning the educational impact of interdisciplinary Learning Factory projects in higher education contexts. In addition, the selected sample was considered capable of providing meaningful insights into how collaborative and experiential learning activities contribute to improving students' professional readiness and competency development aligned with Industry 4.0 and Industry 5.0 educational demands.

### 3.4. Data Collection Method

Data in this study were collected using a structured questionnaire distributed to students who had participated in interdisciplinary Learning Factory projects. The questionnaire was designed to measure re-

spondents' perceptions regarding interdisciplinary collaboration, experiential learning activities, knowledge integration, and student learning outcomes. Each questionnaire item was developed based on indicators derived from previous educational and experiential learning studies to ensure content relevance and measurement accuracy.

The questionnaire utilizes a five-point Likert scale ranging from strongly disagree to strongly agree. The use of the Likert scale enables respondents to express their level of agreement toward each statement systematically and allows the researcher to convert perceptions into quantitative data suitable for statistical analysis.

Table 2. Statistical Analysis Techniques

Statistical Analysis	Purpose
Descriptive Statistics	To summarize respondent characteristics and research data
Validity Test	To evaluate whether questionnaire items accurately measure research variables
Reliability Test	To assess the consistency of the research instrument
Regression Analysis	To examine the influence of interdisciplinary Learning Factory projects on student learning outcomes

Before conducting the main data collection, the research instrument underwent validity and reliability testing to ensure that the questionnaire accurately measures the intended constructs and produces consistent results. Validity testing was conducted to evaluate whether each questionnaire item appropriately represents the corresponding research variable, while reliability testing was performed to assess the internal consistency of the instrument using statistical reliability coefficients.

Table 2 explains the statistical analysis techniques used in this study. Descriptive statistics are applied to provide an overview of respondent characteristics and general data patterns. Validity and reliability testing are conducted to ensure the quality and consistency of the research instrument. Furthermore, regression analysis is used to evaluate the influence of interdisciplinary Learning Factory projects on student learning outcomes and to determine whether the relationship between the variables is statistically significant. These procedures are essential to ensure the credibility, consistency, and accuracy of the collected data before further statistical analysis is conducted.

### 3.5. Data Analysis Technique

After the data collection process was completed, the collected responses were analyzed using statistical analysis techniques. The analysis began with descriptive statistical analysis to summarize respondent characteristics and provide a general overview of the collected data. Descriptive statistics included frequency distributions, mean scores, percentages, and standard deviations to describe respondent perceptions regarding interdisciplinary Learning Factory activities and student learning outcomes.

Following descriptive analysis, regression analysis was conducted to examine the influence of interdisciplinary Learning Factory projects on student learning outcomes. Regression analysis was selected because it enables the researcher to determine the strength and significance of the relationship between the independent and dependent variables. Through this analysis, the study evaluates whether participation in interdisciplinary Learning Factory activities significantly contributes to the improvement of students' competencies and educational performance.

In addition, the statistical analysis process helps identify patterns related to experiential learning effectiveness, interdisciplinary collaboration, and competency development. The findings obtained from the regression analysis are expected to provide empirical evidence regarding the effectiveness of Learning Factory implementation in higher education and support the development of innovative project-based learning strategies aligned with industrial needs.

### 3.6. Research Procedure

The research procedure describes the systematic stages conducted in this study to examine the effect of interdisciplinary Learning Factory projects on student learning outcomes. The procedure was designed to ensure that the research was carried out in a structured and consistent manner, beginning from problem identification until the interpretation of findings and conclusion development. Each stage contributes to ensuring the validity, reliability, and credibility of the research results.

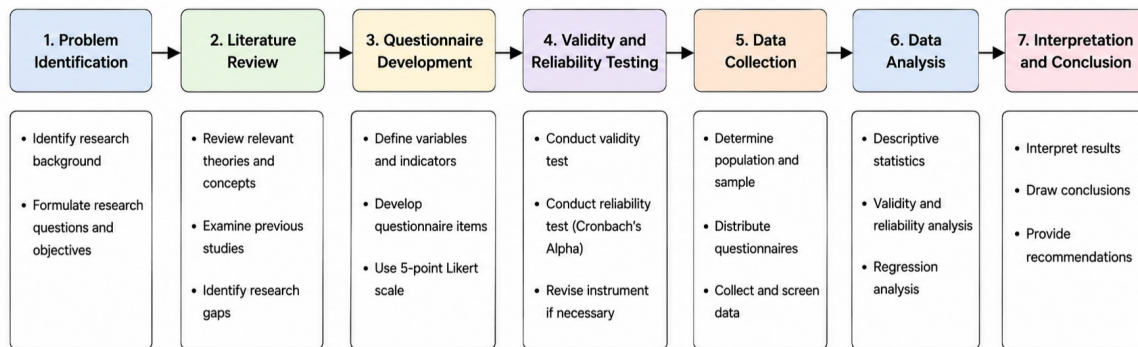


Figure 2. Research Procedure

Figure 2 illustrates the overall research procedure applied in this study. The research process begins with identifying the research problem related to interdisciplinary Learning Factory implementation in higher education environments. After conducting a comprehensive literature review, the researcher develops the conceptual framework and designs the research instrument in the form of a structured questionnaire.

The questionnaire then undergoes validity and reliability testing to ensure measurement quality and consistency before being distributed to respondents. Following the data collection stage, statistical analysis is conducted to evaluate the relationship between interdisciplinary Learning Factory projects and student learning outcomes. Finally, the results are interpreted to generate conclusions regarding the effectiveness of experiential and interdisciplinary learning activities in improving student competencies.

## 4. RESULTS AND FINDINGS

### 4.1. Respondent Profile

The respondents involved in this study consisted of university students who had participated in interdisciplinary Learning Factory projects as part of their academic learning activities. The respondents originated from several academic disciplines, including engineering, information systems, and business programs, which reflects the interdisciplinary nature of Learning Factory implementation in higher education environments. The involvement of students from different academic backgrounds allowed collaborative interaction and knowledge exchange to occur throughout the project implementation process. Most respondents reported having direct experience in project-based activities conducted within simulated industrial environments where teamwork, communication, and practical problem-solving were emphasized. The diversity of respondent backgrounds and learning experiences provided a comprehensive overview of how interdisciplinary Learning Factory projects influence student learning outcomes across multiple fields of study. In addition, the respondents demonstrated varying levels of participation in collaborative activities, experiential learning processes, and interdisciplinary communication, which contributed to richer perspectives regarding the effectiveness of Learning Factory implementation in improving both cognitive and practical competencies.

The respondent characteristics also indicate that interdisciplinary Learning Factory projects create opportunities for students to engage in collaborative knowledge integration and experiential learning activities that closely resemble real industrial practices. Through participation in interdisciplinary project teams, students are exposed to different perspectives, communication styles, and approaches to solving practical problems, which encourages the development of adaptability, teamwork effectiveness, and critical thinking ability. These experiences are particularly important in preparing students to face increasingly dynamic and collaborative professional environments where multidisciplinary cooperation is highly valued. Therefore, the respondent profile supports the relevance of this study in examining the effectiveness of interdisciplinary Learning Factory implementation as an educational strategy for improving student competencies and learning outcomes in higher education institutions.

#### 4.2. Descriptive Analysis of Interdisciplinary Learning Factory Activities

The descriptive analysis results indicate that interdisciplinary Learning Factory projects positively contribute to students' learning experiences, competency development, and overall engagement during the educational process. Most respondents expressed agreement that Learning Factory activities provided meaningful opportunities for experiential learning, interdisciplinary collaboration, and practical knowledge application. Students perceived that the project-based learning environment enabled them to actively participate in solving real-world industrial problems while simultaneously integrating theoretical concepts into practical situations. The experiential nature of Learning Factory activities encouraged students to become more involved in the learning process because they were required to apply analytical thinking, communication skills, and collaborative problem-solving strategies in realistic project scenarios. As a result, students experienced a more dynamic and interactive learning environment compared to conventional lecture-based learning approaches that primarily focus on theoretical instruction.

The collaboration dimension demonstrated particularly strong responses from respondents, indicating that interdisciplinary teamwork significantly contributed to communication effectiveness, mutual understanding, and collective problem-solving ability among students from different academic disciplines. Students reported that interdisciplinary collaboration allowed them to exchange knowledge, discuss alternative ideas, and integrate diverse perspectives when completing project tasks. These collaborative experiences helped students improve interpersonal competencies, adaptability, and teamwork effectiveness, all of which are considered essential skills in modern industrial and organizational environments. Furthermore, respondents indicated that hands-on project activities within the Learning Factory environment strengthened their motivation and learning engagement because they were directly involved in authentic problem-solving situations that reflected real industrial challenges. The ability to connect theoretical concepts with practical implementation also improved students' understanding of academic materials and enhanced their confidence in applying knowledge within realistic contexts. Overall, the descriptive findings suggest that interdisciplinary Learning Factory implementation supports the development of a more active, collaborative, and industry-oriented learning environment that positively influences student competency development and educational experiences.

#### 4.3. Validity and Reliability Analysis

Before conducting the main statistical analysis, validity and reliability testing were performed to ensure that the research instrument accurately measured the intended variables and consistently represented the constructs examined in this study. Validity testing was conducted by evaluating the relationship between each questionnaire item and its corresponding variable dimension to determine whether the instrument appropriately reflected the concepts of interdisciplinary Learning Factory projects and student learning outcomes. The results of the validity analysis indicate that all questionnaire items met the required validity criteria, demonstrating that the instrument effectively represented the dimensions of collaboration, experiential learning, knowledge integration, cognitive skills, problem-solving ability, collaboration competence, and knowledge application. These findings confirm that the questionnaire items were capable of capturing respondents' perceptions regarding the implementation of interdisciplinary Learning Factory activities and their influence on educational outcomes.

Reliability analysis was also conducted to evaluate the consistency and stability of the research instrument using statistical reliability coefficients. The results demonstrate that all variables achieved acceptable reliability levels, indicating that the questionnaire items consistently measured the intended constructs and produced reliable data for further statistical analysis. Ensuring instrument reliability is particularly important because consistent measurements contribute to the credibility and accuracy of the research findings. The successful validity and reliability results indicate that the collected data are suitable for regression analysis and interpretation of the relationship between interdisciplinary Learning Factory implementation and student learning outcomes. Furthermore, the instrument quality strengthens the overall trustworthiness of the study and supports the conclusion that the findings accurately represent students' experiences and perceptions regarding interdisciplinary experiential learning activities in higher education environments.

#### 4.4. Influence of Interdisciplinary Learning Factory Projects on Student Learning Outcomes

The findings of this study indicate that interdisciplinary Learning Factory projects positively influence student learning outcomes across several important educational dimensions. The implementation of collaborative and experiential project-based activities allowed students to actively engage in practical learning processes that integrate theoretical understanding with real-world application. Students participating in interdisciplinary Learning Factory environments demonstrated improvements in communication skills, analytical

thinking, teamwork effectiveness, problem-solving ability, and practical knowledge application. These findings suggest that Learning Factory implementation provides educational experiences that support both cognitive and professional competency development within higher education environments.

The implementation of interdisciplinary Learning Factory projects generated several important educational findings related to collaboration, experiential learning, knowledge integration, and competency development among students. To summarize the major findings identified in this study, Table 3 presents the main themes and their corresponding influence on student learning outcomes.

Table 3. Summary of Research Findings

Main Theme	Observed Findings	Impact on Student Learning Outcomes
Interdisciplinary Collaboration	Students actively collaborated with peers from different academic disciplines during project activities	Improved communication skills, teamwork effectiveness, and collaborative problem-solving ability
Experiential Learning Activities	Students participated directly in hands-on industrial simulation and project-based learning activities	Enhanced practical understanding and knowledge application
Knowledge Integration	Students combined concepts from multiple disciplines to solve practical project challenges	Strengthened analytical thinking and interdisciplinary understanding
Problem-Solving Process	Students evaluated project challenges and developed alternative solutions collaboratively	Improved critical thinking and decision-making ability
Student Engagement	Students demonstrated active participation and higher motivation during Learning Factory implementation	Increased learning engagement and professional readiness

Table 3 summarizes the major findings of this study related to the implementation of interdisciplinary Learning Factory projects and their influence on student learning outcomes. The findings indicate that interdisciplinary collaboration, experiential learning activities, knowledge integration, and collaborative problem-solving contribute positively to improving students' communication skills, analytical thinking ability, practical knowledge application, and professional readiness. In addition, the findings demonstrate that Learning Factory environments encourage active student participation and provide meaningful learning experiences that support both cognitive and practical competency development in higher education contexts.

#### 4.5. Discussion of Findings

The findings of this study confirm that interdisciplinary Learning Factory projects provide significant educational benefits for students in higher education environments and positively contribute to the improvement of student learning outcomes. The positive relationship between interdisciplinary project participation and competency development supports previous studies emphasizing the effectiveness of experiential learning, project-based learning, and interdisciplinary collaboration in developing higher-order thinking skills and practical competencies. The improvement in students' critical thinking and problem-solving abilities aligns closely with experiential learning theory, which suggests that knowledge is more effectively constructed through direct experience, active participation, and reflective learning processes. Within the Learning Factory environment, students are encouraged to engage directly with practical industrial problems, evaluate alternative solutions, and collaborate with peers from different academic disciplines. These experiences create more meaningful learning processes because students are required to apply theoretical knowledge within realistic and dynamic situations rather than merely memorizing conceptual information from classroom instruction.

The findings also demonstrate that interdisciplinary collaboration plays an important role in improving communication skills, teamwork effectiveness, and adaptability among students. Through interaction with peers from different academic backgrounds, students learn how to communicate ideas clearly, negotiate solutions, integrate multiple perspectives, and coordinate collaborative activities more effectively. These competencies are highly relevant to current industrial environments where multidisciplinary teamwork and collaborative

problem-solving are increasingly important. Furthermore, the study indicates that Learning Factory implementation strengthens the integration between theoretical and practical learning by providing opportunities for students to directly apply academic concepts through hands-on project activities. Traditional classroom learning often focuses heavily on theoretical understanding without sufficient practical exposure, whereas Learning Factory environments allow students to gain experiential learning experiences that improve both understanding and confidence in applying knowledge to solve real-world problems. In addition, interdisciplinary project activities encourage students to think more creatively and innovatively because they are exposed to diverse perspectives and alternative approaches to solving complex industrial challenges. Overall, the findings suggest that interdisciplinary Learning Factory implementation represents an effective educational strategy for preparing graduates with competencies that align with the demands of Industry 4.0 and Industry 5.0, particularly in areas related to collaboration, adaptability, innovation, and practical problem-solving ability.

#### 4.6. Implications of Interdisciplinary Learning Factory Implementation

The results of this study provide important implications for higher education institutions seeking to improve the quality, relevance, and effectiveness of their learning environments through more industry-oriented educational approaches. The findings indicate that interdisciplinary Learning Factory implementation can serve as an effective strategy for enhancing student competencies by integrating experiential learning, collaborative activities, and practical problem-solving experiences into the educational process. Universities are therefore encouraged to incorporate more interdisciplinary project-based learning activities into their curricula to better align academic learning with current industrial and professional demands. The implementation of Learning Factory environments allows students to experience authentic industrial simulations that promote active participation, knowledge integration, and competency development, thereby creating more meaningful and applicable learning experiences compared to conventional lecture-centered instruction.

The study also highlights the importance of interdisciplinary collaboration in supporting students' cognitive, interpersonal, and professional development. Learning Factory environments encourage students from different academic disciplines to work collaboratively in solving complex problems, which helps improve communication effectiveness, teamwork ability, and adaptability within multidisciplinary settings. These competencies are increasingly important in modern workplaces where employees are expected to collaborate across different fields of expertise and respond effectively to rapidly changing technological and organizational challenges. Furthermore, the findings suggest that experiential learning activities significantly contribute to increasing student motivation, engagement, and confidence in applying theoretical knowledge to practical situations. Consequently, educators and curriculum developers are encouraged to adopt more active and student-centered instructional approaches that emphasize hands-on learning, collaborative projects, and real-world problem-solving activities. From an industrial perspective, strengthening interdisciplinary Learning Factory implementation in higher education may help reduce the gap between academic preparation and workforce expectations by producing graduates who possess competencies relevant to Industry 4.0 and Industry 5.0 environments. Therefore, the findings of this study may serve as a valuable reference for universities, policymakers, and educational practitioners in designing innovative and industry-oriented learning systems that better prepare students for future professional challenges.

### MANAGERIAL IMPLICATIONS

The findings of this study indicate that interdisciplinary Learning Factory projects provide meaningful educational benefits for improving student competencies through experiential, collaborative, and project-based learning activities. The implementation of Learning Factory environments encourages students to actively participate in interdisciplinary teamwork, practical problem-solving processes, and knowledge integration activities that closely resemble real industrial situations. These learning experiences appear to support the development of communication skills, analytical thinking ability, collaboration effectiveness, adaptability, and professional readiness among students in higher education environments. In addition, students become more actively engaged in the learning process because they are directly involved in practical activities that require collaboration, reflection, and decision-making within realistic project contexts.

The study also suggests that higher education institutions may benefit from integrating more interdisciplinary and experiential learning approaches into their curricula to create learning environments that are more adaptive, collaborative, and industry-oriented. Through interdisciplinary project-based activities, students are provided opportunities to connect theoretical understanding with practical implementation while simulta-

neously interacting with peers from different academic backgrounds. Such experiences may help students develop broader perspectives, stronger teamwork ability, and greater confidence in responding to complex professional and industrial challenges. The implementation of Learning Factory activities may therefore contribute to reducing the gap between academic learning and workplace expectations by exposing students to authentic collaborative and experiential learning situations.

Furthermore, the findings highlight the importance of creating supportive learning environments that encourage active participation, reflective learning, and interdisciplinary interaction throughout the educational process. Educators may play an important role in facilitating collaborative learning experiences by guiding students through project activities, encouraging communication among team members, and supporting practical problem-solving processes. Universities may also consider strengthening collaboration with industry partners to provide more authentic project experiences and practical industrial exposure for students. Therefore, the implementation of interdisciplinary Learning Factory activities may contribute positively to the development of more meaningful, student-centered, and professionally relevant learning systems in higher education institutions while simultaneously supporting the development of competencies relevant to Industry 4.0 and Industry 5.0 environments.

## CONCLUSION


This study concludes that data driven decision making practices play a significant role in enhancing training effectiveness, improving learner engagement, and supporting adaptive learning processes within learning factory environments. The findings demonstrate that stakeholders actively use data from learning analytics systems, performance dashboards, and institutional reports to guide instructional strategies, monitor learner progress, and optimize operational planning. The study reveals that successful implementation of data driven practices is strongly influenced by organizational culture, leadership support, data literacy, and the availability of integrated technological infrastructures. At the same time, the research highlights that decision making in learning factories is not purely technical but involves continuous reflection, collaboration, and interpretation of contextual information. Overall, the study shows that when data is effectively interpreted and integrated into daily practices, learning factories can achieve better alignment between educational outcomes and industry requirements, thereby supporting more responsive and evidence informed training environments.


This research answers the central question of how stakeholders understand and implement data driven decision making by showing that decision processes are shaped by both formal data systems and informal collaborative practices. Stakeholders interpret data differently based on their roles, yet collective discussions and feedback mechanisms help translate data into actionable insights that improve training quality. However, the study also identifies several limitations. The research is based on qualitative data from a limited number of learning factory settings, which may restrict the generalizability of findings to other contexts. Additionally, variations in technological maturity across cases may influence how data practices are perceived and implemented. The reliance on self reported experiences may also introduce subjective bias, although triangulation was used to mitigate this issue. These limitations suggest that while the findings provide valuable insights, further investigation is needed to broaden understanding across diverse environments.

Future research is recommended to expand the scope by including a larger number of learning factories across different industries and geographical contexts to enhance generalizability. Quantitative studies could complement qualitative insights by examining measurable impacts of data driven decision making on performance outcomes such as skill acquisition, productivity, and learner satisfaction. Researchers are also encouraged to explore the integration of emerging technologies such as artificial intelligence driven analytics and real time monitoring systems to better understand their potential in supporting decision processes. Additionally, longitudinal studies would provide deeper insights into how data practices evolve over time and how organizational learning influences the sustainability of data driven initiatives. Such future investigations will contribute to strengthening theoretical frameworks and providing practical guidance for institutions seeking to implement effective data informed training systems.

## 5. DECLARATIONS

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## 5.2. Author Contributions

Validation was conducted by: AV. Conceptualization was completed by: EP. The methodology was developed by: LS. Formal analysis was performed by: AV. Writing, review, and editing were carried out by: LS. Visualization was completed by: EP. All authors, including: AV, EP, and LS, have reviewed and approved the final version of the manuscript.

## 5.3. Data Availability Statement

The corresponding author can provide the data supporting this study upon reasonable request.

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## 5.5. Declaration of Competing Interest

The authors declare that there are no known financial, professional, or personal relationships that could have influenced the results or interpretations presented in this study.

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