

Multidisciplinary Approach Strategies In Electropneumatics Course Learning In The Metaverse Era

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ABSTRACT

A multidisciplinary approach has become an important strategy in vocational education to prepare graduates who are adaptable to the demands of 21st-century industry. This study offers a novel contribution by developing a multidisciplinary vocational learning model that integrates Project-Based Learning (PjBL) and Contextual Teaching and Learning (CTL) within a metaverse-oriented learning environment. The model connects real industrial automation problems, collaborative project activities, contextual learning experiences, and digital simulation to enhance students' technical competence, critical thinking, collaboration, creativity, and professional character. This article examines the implementation and effectiveness of the multidisciplinary strategy in the Electropneumatics course. The research employed a qualitative case study approach, with data collected through interviews, observations, and documentation. The findings indicate that the integration of PjBL and CTL provides meaningful learning experiences by linking theoretical concepts with real industrial applications and digital simulation environments relevant to the Metaverse era. This approach not only improves technical learning outcomes but also fosters responsibility, discipline, teamwork, adaptability, and problem-solving skills. However, its implementation faces several challenges, including human resource readiness, cross-disciplinary curriculum alignment, lecturer competence in digital learning design, and adequate access to digital infrastructure. Therefore, continuous evaluation and synergy among academia, industry, and government are needed to support sustainable implementation. Overall, this multidisciplinary learning model contributes to the development of innovative, contextual, and industry-relevant vocational education, particularly in preparing excellent workers in the field of industrial automation.

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INTRODUCTION

The 21st century has brought major changes in the educational paradigm, triggered by the integration of digital technology and the demands of the Industrial Revolution 4.0 and the Society 5.0

era (DPSMK, 2019; Nur et al., 2022; Siahaan, 2022). These changes require a reorientation of the curriculum and pedagogical approaches that are more adaptive and innovative (Yoto et al., 2024). The integration of technologies such as AI, IoT, and VR is key to creating personalized and interactive learning experiences, while increasing student engagement and meeting diverse learning needs (Arifudin, 2024; Kumbo et al., 2023; Maria Melo de Lima Santos & Albuquerque Silva, 2024; Tene et al., 2024). In addition, digital pedagogical methodologies are considered important in shaping 21st-century skills such as critical thinking, collaboration, and digital (Kusmarni, 2019; Siahaan, 2022). Therefore, higher education institutions are encouraged to align their curricula with the needs of industry and society, with a focus on STEM education and character development (Hasnida et al., 2024; Hwang, 2022; Izadinia, 2023).

The integration of digital technology in education, particularly through the use of the metaverse, reflects a significant shift in the pedagogical paradigm in the 21st century. This transformation is driven by the demands of the Fourth Industrial Revolution and Society 5.0, which require a reorientation of the curriculum and adaptive and innovative teaching strategies. The metaverse offers an immersive learning experience through realistic 3D environments that combine the real and virtual worlds, allowing students to actively engage in the learning process through avatars (Crivellaro & Mandaio, 2023). This approach not only increases engagement and knowledge retention, but also opens up space for personalized learning and global collaboration between students from different regions (Hasnida et al., 2024; Suhird, 2021). However, the application of the metaverse in education faces various challenges, including the need for adequate digital infrastructure, training for educators, and the risk of widening the digital divide (Akbar et al., 2024). Therefore, the use of this technology must be accompanied by a strategic approach that can ensure fair access and effective implementation in diverse educational contexts.

The metaverse offers significant opportunities in practice-based vocational education such as electro-pneumatics, as these competencies are central to industrial automation, which requires mastery of pneumatics, electrical systems, sensors, actuators, control logic, and problem-solving in production systems. However, Electro-Pneumatics learning still relies heavily on physical laboratories, which are limited in terms of the number of tools, practice time, maintenance costs, as well as the risks of assembly errors and workplace safety. Meanwhile, previous research has primarily addressed the metaverse in general within education, such as virtual classrooms, digital simulations, or online collaboration, but few studies have specifically examined the integration of the metaverse into Electro-Pneumatics learning combined with Project-Based Learning (PjBL) and Contextual Teaching and Learning (CTL). This gap forms the basis of this study: the need for an integrated vocational learning model that connects the metaverse, collaborative projects, contextual learning, and industrial control system competencies. Through VR and AR technologies, the metaverse enables students to simulate circuits, observe actuator operations, test control logic, and understand complex concepts in a safe environment without the risks associated with direct use of physical tools (Zhang, 2024), while also opening opportunities for cross-

regional collaboration (López-Belmonte et al., 2023). However, its implementation still requires human resource readiness, digital infrastructure support, equitable access to technology, as well as privacy protection and data security (Jagatheesaperumal et al., 2024; Santiago et al., 2024).

Preliminary observations conducted by researchers at Makassar State University's Mechanical Engineering Education department found that there is an Electro-Pneumatic course oriented towards learning in the Metaverse era. Electro-Pneumatics, as part of industrial automation systems, is a strategic course in engineering study programs because it is directly related to the mastery of control systems based on a combination of electricity and air pressure. Mastery of skills in designing, analyzing, and operating electro-pneumatic systems is an important asset for engineering graduates to be able to compete in the industrial world. However, in practice, many educational institutions face challenges such as limited facilities, limited practice time, and a gap between theory and real-world application.

Multidisciplinary Design Literature in Vocational Education

Multidisciplinary design in the context of vocational education is an approach that integrates various disciplines to create a more holistic and relevant learning experience (Romadin, 2021; Siahaan, 2022). This approach is very important in the modern era, where the complexity of challenges in the world of work requires broad and diverse skills and knowledge (Supardi et al., 2025). In vocational education, multidisciplinary design focuses not only on mastering technical skills, but also on developing soft skills and understanding social, economic, and cultural contexts.

One of the main aspects of multidisciplinary design is collaboration between various disciplines (A'la et al., 2023; Hakim & Abidin, 2024). In vocational education, this means involving teaching staff from different backgrounds, such as engineering, management, arts, and social sciences (Munir et al., 2022; Wardina et al., 2019). This way, students can gain broader insights into how different fields interact and contribute to solving complex problems. For example, in an engineering education program, students not only learn about engineering principles but also about project management and effective communication.

Technology integration is also an integral part of multidisciplinary design (SULFIANA & TANG, 2024; Suryadi & Jasiah, 2023). With rapid technological advances, the use of digital tools in learning has become very important. The TPACK (Technological Pedagogical Content Knowledge) concept emphasizes the importance of combining content knowledge, pedagogy, and technology to create an engaging and effective learning experience (Drakuli & Karad, 2015; Nurmalasari et al., 2023; Wijayanto & Utomo, 2023). In the context of vocational education, the application of TPACK enables teachers to design curricula that not only teach practical skills but also prepare students to adapt to technological changes in the workplace (Otero et al., 2023; Yang et al., 2020). Multidisciplinary design also supports the development of 21st-century skills, such as creativity, collaboration, and problem solving (Semradova & Hubackova, 2016). Through collaborative projects and problem-based learning, students are encouraged to work together in groups, share ideas, and find innovative solutions to real

challenges. This approach not only enhances their academic understanding but also equips them with the social skills needed in the workplace.

In its implementation, vocational education must take into account the needs of industry and developments in the job market. Through collaboration with industry, educational programs can be designed to meet the specific demands of certain sectors. This creates relevance between the curriculum taught in the classroom and the skills required by employers. A multidisciplinary design in vocational education offers a comprehensive approach to preparing students for the increasingly complex challenges of the world of work. By integrating various disciplines and technologies and focusing on the development of practical and social skills, vocational education can produce graduates who are ready to compete and contribute effectively to society.

Table 1. Advantages of a Multidisciplinary Approach

No.	Advantage	Description
1.	More comprehensive problem solving	A multidisciplinary approach allows a problem to be analyzed from various perspectives so that the resulting solution is more comprehensive.
2.	Enhanced creativity and innovation	Collaboration between fields of study helps broaden perspectives in understanding a phenomenon.
3.	Expanded insight and understanding	Collaboration between fields of study helps broaden perspectives in understanding a phenomenon.
4.	Efficiency in problem solving	By combining expertise from various fields, the problem-solving process becomes more efficient.
5.	Improved collaboration and cooperation	This approach encourages cooperation between individuals with different scientific backgrounds, strengthening synergy within the team.
6.	Greater adaptability to complex challenges	Today's world faces complex problems, and a multidisciplinary approach can provide more flexible and adaptive solutions.
7.	Enhanced competitiveness in the workplace	Individuals with multidisciplinary skills are better prepared to face the challenges of a workplace that requires cross-disciplinary skills.

(Source: Otero et al., 2023; Siahaan, 2022)

METHOD

The case study type in the qualitative approach is used to identify problems based on real data, involving several research subjects. The case taken by the researcher was located in the Mechanical Engineering Education Department of UNM in the Electropneumatic Practicum course in the odd semester of the 2025/2026 academic year. The presence of researchers at the research location in the qualitative research concept requires researchers to be present in the field of research (Hollweck, 2016; Ulfatin, 2015). The data sources in this study consisted of: The Chair of the Mechanical Engineering Department, the Chair of the Mechanical Engineering Program, one lecturer in electro-pneumatics, and two students. The steps taken by the researcher after data collection included: (1) data reduction; (2) coding of the research focus, and (3) data analysis. For data analysis and validity checking, the researcher chose to use the degree of confidence or credibility by triangulating data sources and methods. Data analysis began with individual cases and continued with cross-case data (Figure 1).

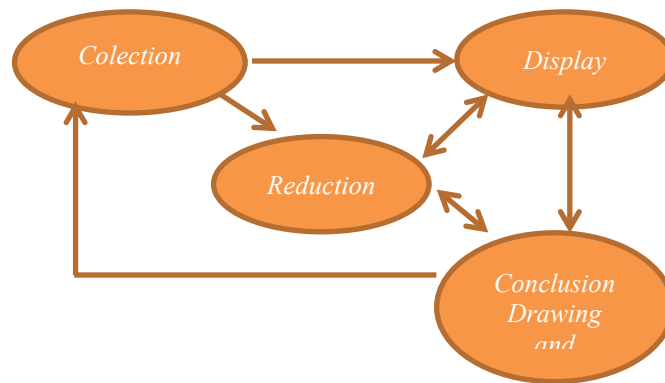


Figure 1. Interactive Cycle of Research Data Analysis Process

The research data and data collection indicators are explained in Table 2.

Table 2. Data Collection and Coding Guidelines

No.	Research Indicator	Code	Data Collection Technique	Code	Data Source	Code	Reduction Results
1.	Multidisciplinary Learning Design	DPM	In-depth Interviews	WM	Department Head	KJ	DPM-WM-KJ
					Program Head	KK	DPM-WM-KK
					Pnumatic Lecturer	DP	DPM-WM-DP
				Student 1	MHS1	DPM-WM-MHS1	
				Student 2	MHS2	DPM-WM-MHS2	
				Observations Documentation	O	Portfolio Data	P
		D	Photo	F	DPM-D-F		
2	SWOT Analysis of Multidisciplinary Learning	SPM	In-depth Interviews	WM	Department Head	KJ	SPM-WM-KJ
					Program Head	KK	SPM -WM-KK
					Pnumatic Lecturer	DP	SPM -WM-DP
				Student 1	MHS1	SPM -WM-MHS1	
				Student 2	MHS2	SPM -WM-MHS2	
				Observations Documentation	O	Portfolio Data	P
		D	Photo	F	SPM -D-F		
3.	Evaluation of Multidisciplinary Learning	EPM	In-depth Interviews	WM	Department Head	KJ	EPM-WM-KJ
					Program Head	KK	EPM -WM-KK
					Pnumatic Lecturer	DP	EPM -WM-DP
				Student 1	MHS1	EPM -WM-MHS1	
				Student 2	MHS2	EPM -WM-MHS2	
				Observations Documentation	O	Portfolio Data	P
		D	Photo	F	EPM -D-F		

RESULTS AND DISCUSSION

Multidisciplinary Learning Design

Research findings indicate that a multidisciplinary approach in vocational education is a key strategy for preparing graduates who are adaptable, innovative, and ready to face the challenges of the modern workplace. The integration of various disciplines, cross-sector collaboration, and the development of soft skills are essential elements in building a relevant and competitive vocational education system. Multidisciplinary and transdisciplinary approaches can address the fragmentation of academic disciplines, provide a more holistic understanding, and strengthen problem-solving, collaboration, and leadership skills.

Research findings also indicate that strategies commonly used in multidisciplinary learning include project-based learning, team teaching, industry-academic collaboration, and the integration of

digital technologies such as e-learning and augmented reality. Learning models such as the Student Business Center and Modern Industrial College demonstrate that real-world learning experiences can strengthen cross-disciplinary collaboration and the development of students' soft skills.

Table 1. Focus on Multidisciplinary Strategies in Vocational Education

No	Strategic Focus	Examples of Implementation	Key Impacts	Code
1	Project Learning	Student Business Center	Collaboration, soft skills	DPM-WM-KJ
2	Industry Collaboration	Modern Industrial College	Technology adaptation, relevance	DPM-WM-KK DPM-WM-DP
3	Digital Integration	E-learning, AR	Real-world simulation	DPM-WM-MHS1
4	Team Teaching	multidisciplinary science	Tolerance, leadership	DPM-WM-MHS2 DPM-O-P DPM-D-F

In addition, the study found that the main barriers to implementing multidisciplinary learning include limited time for collaboration, group dynamics, overlapping teacher roles, and unequal access to technology. The success of multidisciplinary strategies is heavily influenced by teacher professional development, policy support, and the active involvement of industry and the community.

Multidisciplinary learning design in vocational education requires planned cross-disciplinary integration to make learning more relevant to the needs of modern industry. This integration includes collaboration between technical, social, and managerial aspects in a single learning activity, which emphasizes not only technical skills but also critical and collaborative thinking skills. The Project-Based Learning model effectively increases student motivation, engagement, and learning outcomes because it allows them to apply various disciplines in real projects (Panca, 2023). The application of Contextual Teaching and Learning (CTL) increases student active participation and the ability to connect theoretical concepts with the industry context (Juliwardi, 2021). This multidisciplinary approach strengthens the relevance of vocational learning to the world of work while fostering student creativity and adaptability to changes in industry 4.0 technology.

The implementation of multidisciplinary learning designs in vocational education faces various challenges, especially in terms of alignment between learning objectives, basic competencies, and the needs of the industrial world. The alignment between learning objectives and basic competencies in vocational schools has only reached 65.03%, indicating the need for improvements in adaptive curriculum planning (Budiastuti et al., 2021). In addition, the readiness of teachers to implement interdisciplinary learning is also a key factor. It is important for teachers to use best practices in integrating various learning models so that the learning process remains effective and contextual to the work environment (Dewi, 2022). Classroom action research-based educational innovation plays an important role in improving the quality of learning designs that are responsive to the needs of the 21st century (Ely et al., 2023). Therefore, multidisciplinary design requires not only interdisciplinary collaboration but also comprehensive learning management and evaluation strategies to be effective in shaping sustainable work competencies.

In conclusion, a multidisciplinary approach in vocational education is a transformative strategy that can bridge the gap between education and the needs of modern industry. Cross-disciplinary integration through models such as Project-Based Learning, Contextual Teaching and Learning, team teaching, and industry-academic collaboration has been proven to increase student motivation, creativity, and critical thinking skills. This approach not only strengthens technical skills but also fosters soft skills such as collaboration, leadership, and adaptability, which are highly needed in the Industry 4.0 era. However, challenges such as curriculum alignment, teacher readiness, and infrastructure limitations still need to be addressed through improving the professional capacity of educators, collaborative policy support, and strengthening synergies between schools, the business world, and industry. Thus, multidisciplinary learning design is an important foundation for realizing relevant, innovative, and globally competitive vocational education.

SWOT of Multidisciplinary Learning

The results of the SWOT analysis of multidisciplinary learning are illustrated in the following figure 2.

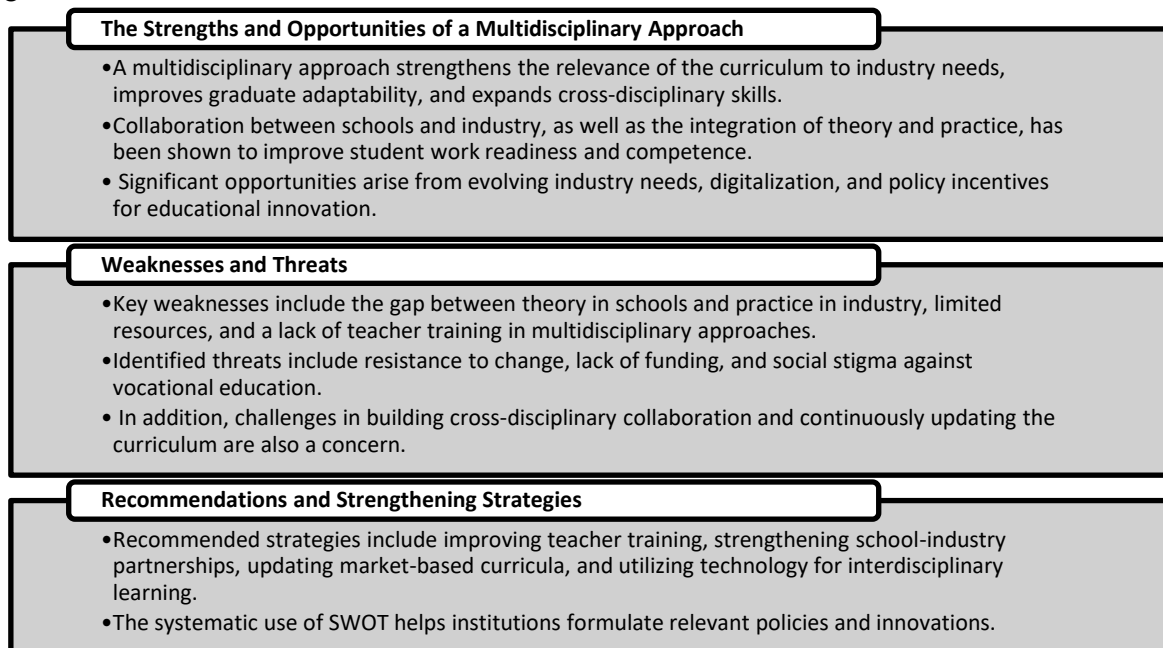


Figure 2. SWOT of Multidisciplinary Learning

(Source: SPM-WM-KJ; SPM -WM-KK; SPM -WM-DP; SPM -WM-MHS1; SPM -WM-MHS2; SPM -O-P; SPM -D-F)

Figure 2 shows that the results of the SWOT analysis indicate that the strengths of multidisciplinary learning lie in the improvement of teacher competencies, the relevance of the curriculum to the needs of the workforce, and the ability to connect various fields of study. This approach helps teachers design learning experiences that are more reflective, contextual, and aligned with both student characteristics and industry needs.

Opportunities for developing multidisciplinary learning are evident in the availability of ongoing professional development, the use of educational technology, school community engagement,

and collaboration with the business and industrial sectors. However, weaknesses and threats remain, including teachers' limited ability to develop cross-disciplinary competency indicators, insufficient digital infrastructure, budget constraints, administrative burdens, and suboptimal synergy between schools, industry, and the community. The implementation of the learning process is illustrated in Figure 3.

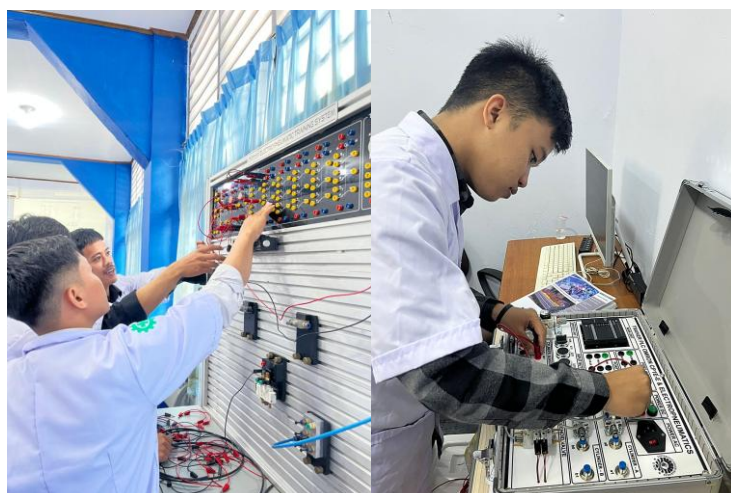


Figure 3. Electropneumatic Learning Activity
(Source: DPM-O-P; SPM -O-P; EPM -O-P)

A SWOT analysis of multidisciplinary learning in vocational education shows that its main strengths lie in improving teacher competence and the relevance of the curriculum to the needs of the world of work. Through SWOT analysis training, teachers are able to design learning that is more reflective, innovative, and contextual to classroom conditions, so that they can identify strengths and obstacles in the learning process more accurately (Ikka et al., 2025). In addition, the digitization of learning, such as the use of offline digital media using DVD-RW in areas with limited internet access, expands access and strengthens the integration of different fields of study (Alfiandri et al., 2021). Multidisciplinary integration is also considered effective in strengthening students' critical, collaborative, and applicative thinking skills in relation to industrial issues, in line with the direction of vocational education transformation that emphasizes cross-disciplinary skills and work readiness (Sumarwati et al., 2025). Thus, the strength of multidisciplinary learning lies in the combination of improving teachers' pedagogical competencies and utilizing technology that is adaptive to the local conditions of vocational schools.

However, weaknesses and threats remain factors that need to be considered in order for the implementation of multidisciplinary learning to run optimally. The main weakness lies in the limitations of teachers in developing indicators of cross-disciplinary competency achievement and in managing learning that combines theory and industry practice (Muslikhah et al., 2022). External obstacles such as budget constraints, digital infrastructure limitations, and administrative burdens also often hinder the smooth implementation of this collaborative learning model (Alfiandri et al., 2021). Nevertheless, opportunities remain open through continuous professional training that improves teachers' capacity to

apply multidisciplinary strategies and support from the school community and society that strengthens learning collaboration (Ikka et al., 2025; Sumarwati et al., 2025). Therefore, efforts to strengthen the implementation of multidisciplinary learning in vocational schools need to focus on developing teacher competencies, optimizing digital facilities, and creating synergy between schools, industry, and the educational community.

In conclusion, a multidisciplinary approach in vocational education has great potential to improve the relevance and quality of learning through cross-disciplinary integration that is in line with the needs of the modern world of work. The SWOT analysis results show that the main strengths of this approach lie in improving teacher competencies and applying adaptive learning technologies, such as offline-based digitization that supports equitable access in various school conditions. However, limitations in teacher competencies in managing interdisciplinary learning, lack of digital infrastructure, and administrative constraints remain major challenges that need to be overcome. By strengthening continuous training for teachers, optimizing digital facilities, and fostering close collaboration between schools, industry, and the community, multidisciplinary-based vocational education can become an effective strategy in producing graduates who are ready to work, adaptive, and innovative in facing the challenges of an ever-changing industrial world.

Multidisciplinary Learning Evaluation

The results of the multidisciplinary learning evaluation are illustrated in the following figure 4.

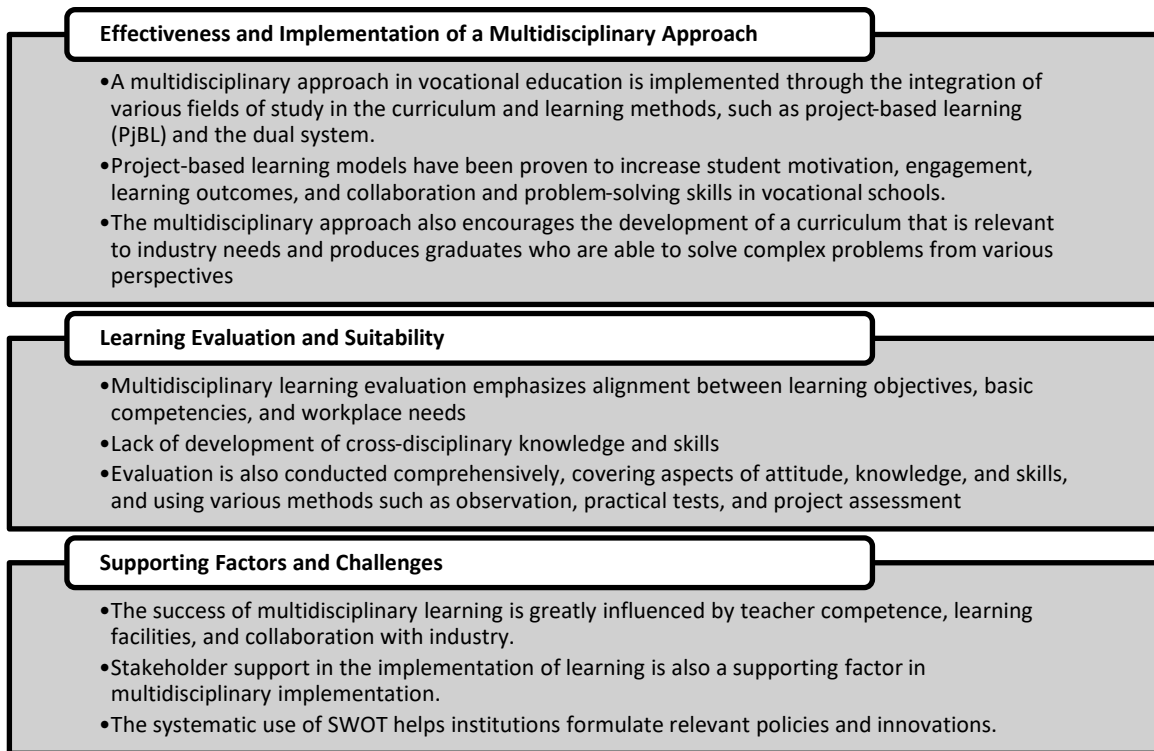


Figure 4: Evaluation of Multidisciplinary Learning

(Source: EPM-WM-KJ; EPM -WM-KK; EPM -WM-DP; EPM -WM-MHS1; EPM -WM-MHS2; EPM -O-P; EPM-D-F)

Research findings indicate that assessments of multidisciplinary learning evaluate not only students' mastery of knowledge but also their ability to think critically, collaborate, communicate, solve problems, and generate solutions relevant to the workplace. These assessments are crucial because multidisciplinary learning emphasizes the integration of attitudes, knowledge, skills, and real-world experiences.

The research findings also indicate that project-based learning and learning systems connected to the industrial world can enhance students' motivation, engagement, and work readiness. However, evaluation still faces challenges in the form of inconsistencies between learning objectives, core competencies, content, methods, and assessment tools. Therefore, multidisciplinary evaluation needs to be designed more comprehensively to effectively measure students' achievements holistically.

The integration of various disciplines through the Project-Based Learning (PjBL) model creates a more contextual learning experience, fosters motivation, and improves students' critical and collaborative thinking skills. The application of PjBL in productive courses significantly increases students' motivation, engagement, and problem-solving skills (Panca & Exwan, 2023). In addition, the dual system implemented in various vocational schools strengthens the relationship between theory and practice, so that students gain learning experiences that are relevant to the actual industrial situation (Handa, Erwani & Gatot, Sutapa Yuliana, Masluyah, 2023). These findings confirm that a multidisciplinary approach not only improves learning outcomes but also produces graduates who are competent and adaptable to the dynamics of the modern workplace.

Multidisciplinary learning evaluation requires alignment between learning objectives, basic competencies, and industry needs. Comprehensive evaluation, which includes assessing attitudes, knowledge, and skills, is also an important factor in assessing student achievement holistically (Yulianti et al., 2021). However, the main challenges faced include the readiness of teachers to apply a cross-disciplinary approach and limited supporting facilities. The success of multidisciplinary learning requires support from interdisciplinary collaboration, strengthening teacher competencies, and the involvement of the industrial world so that vocational learning is truly relevant to the needs of the workplace (Rahmah, Husnul Yaqin, 2024).

In conclusion, the evaluation of multidisciplinary learning in vocational education is a strategic instrument to ensure that the integration of disciplines truly supports the achievement of contextual learning objectives that are oriented towards industry needs. The results of the study show that the application of a multidisciplinary approach, especially through the Project-Based Learning model and the dual system, can increase student motivation, engagement, and critical and collaborative thinking skills, thereby producing graduates who are more adaptive to the modern world of work. However, there are still challenges in the form of a low level of alignment between learning objectives and basic competencies, as well as limitations in facilities and teacher readiness in integrating various disciplines. Therefore, strengthening teacher capacity, optimizing learning facilities, and enhancing synergy

between schools and industry are key to strengthening the effectiveness of multidisciplinary learning implementation in vocational education.

CONCLUSION

A multidisciplinary approach in vocational education has proven to be an effective strategy in preparing graduates who are competent, adaptive, and relevant to the needs of the 21st century workplace. The integration of cross-disciplinary knowledge, industry-academic collaboration, and the application of innovative learning models such as Project-Based Learning (PjBL) and Contextual Teaching and Learning (CTL) strengthen students' critical, collaborative, and creative thinking skills. In addition, the integration of digital technology through e-learning and augmented reality helps create a learning experience that is contextual and realistic to the industrial world. Thus, multidisciplinary learning not only improves the quality of learning outcomes but also fosters professional character that is ready to face the complexities of the modern world of work.

However, the success of implementing this approach is highly dependent on the readiness of human resources, curriculum alignment, and educational policy support. Challenges such as limited collaboration time, teacher readiness in managing interdisciplinary learning, and access to digital infrastructure need to be addressed immediately through continuous professional development and synergy between schools, industry, and government. Continuous evaluation is also necessary so that multidisciplinary learning can continue to adapt to changes in industry and technology needs. Overall, the multidisciplinary approach in vocational education is an important foundation in building a relevant, innovative, and sustainable education system to produce a generation of excellent workers in the era of globalization.

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