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A Phenomenology of Project Based Learning in Vocational Analytical Chemistry Education

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***Abstract*:** *This study aims to explore the challenges, strategies, and impacts of implementing Project-Based Learning (PjBL) in the Analytical Chemistry program at Vocational High Schools (SMK). Using a qualitative phenomenological approach, data were collected through interviews, observations, and documentation involving teachers and students actively engaged in PjBL activities. The analysis followed Moustakas's phenomenological steps, including data reduction, categorization, and interpretation. The findings revealed three key themes: (1) resource and infrastructure limitations, (2) teachers' adaptive and innovative strategies, and (3) students' creativity and entrepreneurial motivation. Despite facing financial and facility constraints, teachers demonstrated resilience by utilizing local resources, modifying learning designs, and applying reflective assessment. Students, in turn, showed high creativity and problem-solving skills by developing innovative chemical-based products that integrated environmental awareness and entrepreneurship. The study concludes that PjBL effectively enhances students' higher-order thinking, creativity, and motivation in vocational chemistry learning. However, its sustainability depends on institutional support, adequate funding, and collaboration with industry. These findings highlight the importance of developing structured, project-based digital modules to strengthen teacher competence and ensure meaningful, future-oriented learning in vocational education.*

***Keywords*:** *project-based learning; analytical chemistry; vocational education; creativity; entrepreneurial motivation*

INTRODUCTION

The 21st century demands that students possess critical thinking, creative thinking, collaboration, communication skills, and technological literacy. These competencies are known as the 4Cs (Critical Thinking, Creativity, Collaboration, Communication) and form the foundation of the *Kurikulum Merdeka* (Kemendikbudristek, 2022). In the context of Vocational High Schools (Sekolah Menengah Kejuruan/SMK), these skills must be integrated with entrepreneurial spirit so that graduates are able to compete in the workforce and create independent business opportunities (Sinaga et al., 2019; Siregar et al., 2021).

Analytical Chemistry is one of the core competencies in the SMK Analytical Chemistry program, emphasizing practical, laboratory, and applicative skills (Setiawan, 2017). The *Kurikulum Merdeka* encourages the implementation of Project-Based Learning (PjBL) as the main instructional approach. According to Lee and Blanchard (2019), PjBL can enhance student motivation by providing real-life learning experiences. Thomas (2000) explains that PjBL develops problem-solving and collaboration skills, while Bell (2010) highlights its potential in preparing students for 21st-century challenges. PjBL has also been proven to strengthen creativity, critical thinking, and entrepreneurial motivation in chemistry learning (Rosello et al., 2018; Lubis & Manurung, 2020; Sitorus et al., 2021).

However, the implementation of PjBL in vocational analytical chemistry programs still faces various obstacles. Teachers reported limitations in laboratory equipment, insufficient chemicals, and financial constraints, causing both teachers and students to use personal resources for project execution. Schools do provide limited support, such as cooperatives and exhibition spaces, but the funding allocation remains inadequate. Similar conditions were also found by Naibaho & Silaban (2022), who reported that limited infrastructure and materials significantly affect the continuity of laboratory-based learning in SMK chemistry programs.

Nevertheless, teachers continue to demonstrate adaptability and commitment by integrating locally available materials into projects and encouraging students to produce innovative chemical products. This aligns with findings by Situmorang et al. (2018) and Simanjuntak & Manurung (2021), who emphasized that contextual learning and creative use of local resources can improve student engagement and entrepreneurial attitude. Meanwhile, students showed strong enthusiasm and creativity, experimenting with natural ingredients to create products such as soap, perfume, or eco-enzymes. However, such creativity has not been fully facilitated through structured and innovative learning media (Sitorus & Silaban, 2023).

This condition reflects a gap between the actual and ideal situations. The actual condition involves limited funds, facilities, and learning media, whereas the ideal condition is characterized by creative, interactive, and well-supported project-based learning. Similar findings have been observed in studies highlighting the need for innovative instructional media to strengthen students' analytical and entrepreneurial competencies in chemistry (Panggabean et al., 2017; Situmorang et al., 2018; Sitorus et al., 2021).

Therefore, it is crucial to explore teacher challenges and strategies, as well as student creativity and motivation, in the implementation of PjBL within the SMK Analytical Chemistry program. This research provides empirical insights that can serve as the foundation for developing innovative project-based digital modules to enhance vocational chemistry learning effectiveness (Anjarwati et al., 2016; Herga et al., 2016).

LITERATURE REVIEW

Vocational education aims to prepare graduates with practical skills in line with the demands of the workforce (Permendikbud No. 34 of 2018). In addition to technical competencies, vocational high school (*SMK*) students are also required to develop an entrepreneurial mindset (Sulistiyani & Rachman, 2020; Fayolle & Gailly, 2015). Dewi & Mulyatiningsih (2013) found that entrepreneurial experiences positively influence students' motivation to pursue entrepreneurship.

The *Kurikulum Merdeka* emphasizes Project-Based Learning (PjBL) as a key learning strategy for 21st-century education (Kemendikbudristek, 2022). PjBL is a learning model that encourages students to produce tangible products through project completion. Lee & Blanchard (2019) argue that PjBL can enhance motivation in science learning, while Thomas (2000) and Bell (2010) emphasize its effectiveness in preparing students to face 21st-century challenges.

PjBL is a teaching strategy that emphasizes tangible outcomes through project implementation (Kemendikbudristek, 2022; Krajcik & Blumenfeld, 2006). Research has shown that PjBL enhances learning motivation (Lee & Blanchard, 2019), critical thinking (Thomas, 2000), collaboration (Bell, 2010), and creativity (Rosello et al., 2018). In the context of vocational education, PjBL is relevant because it connects theory with practice while fostering entrepreneurship (Pujiyono et al., 2015). In addition, Arifin and Nisa (2021) found that project-based learning significantly enhances higher-order thinking skills when supported by authentic assessment and reflective activities

Project-Based Learning (PjBL) is widely recognized as a pedagogical approach that emphasizes learning through real-world projects, enabling students to integrate theoretical understanding with practical experience (Thomas, 2020; Krajcik & Shin, 2018). In vocational analytical chemistry education, this approach is particularly relevant because it reflects the authentic processes of laboratory work and industrial chemical analysis (Situmorang et al., 2019; Rahmadani & Silaban, 2021). PjBL allows students to not only acquire scientific knowledge but also to develop essential 21st-century competencies such as creativity, collaboration, and self-regulation (Aini et al., 2022).

However, the implementation of PjBL in SMK faces significant obstacles, including limited equipment, materials, funding, and structural support (Situmorang et al., 2018; Herga et al., 2016; Anjarwati et al., 2016). Teachers often resort to improvisation, such as substituting chemicals, using personal funds, or utilizing simple facilities (Widodo et al., 2020). Nevertheless, such solutions are unsustainable. Teachers often encounter constraints related to limited laboratory resources, time allocation, and assessment complexity (Lee & Blanchard, 2019; Hutabarat & Silaban, 2020). Furthermore, teachers are expected to play multiple roles—as facilitators, mentors, and evaluators—requiring pedagogical adaptability and creativity to ensure that students can successfully complete projects that simulate industrial practices (Mahmood et al., 2021). Such contextual challenges highlight the need to explore the teachers' lived experiences in managing and sustaining PjBL in chemistry vocational classrooms.

Creativity and critical thinking are classified as Higher Order Thinking Skills (HOTS), which are essential for vocational students (Anderson & Krathwohl, 2010). Innovative learning approaches, such as concept mapping and creative projects, have been proven to improve students' analytical skills (Rosello et al., 2018; Panggabean et al., 2017).

Creativity also plays a central role in the success of PjBL. It enables students to generate novel ideas, design innovative solutions, and adapt to laboratory challenges (Sari et al., 2019; Aini et al., 2022). However, creativity does not arise spontaneously—it is often stimulated through teachers' scaffolding strategies and a supportive learning environment (Kolb & Kolb, 2020). Despite this, most literature focuses on creativity as a learning *outcome* rather than as a *process* that develops through project experiences in chemistry vocational education.

Entrepreneurial motivation emerges when students are directly involved in production and marketing processes (Fayolle & Gailly, 2015; Pujiyono et al., 2015). In SMK Analytical Chemistry, student motivation increases when they receive recognition through exhibitions or product sales (Suryani et al., 2021).

Thomas (2000) highlighted that PjBL enhances motivation by making learning more meaningful. Bell (2010) added that PjBL prepares students for 21st-century challenges by integrating problem-solving and teamwork skills. In the context of SMK Analytical Chemistry, PjBL is crucial as it bridges laboratory theory with the development of economically valuable chemical products.

Motivation is a key factor influencing students' success in project-based learning. According to Self-Determination Theory (Deci & Ryan, 2017), learning motivation develops when students experience autonomy, competence, and social relatedness in their learning environment. In a vocational chemistry context, motivation is often shaped by students' perception of the relevance between learning tasks and their future professional goals (Gopalan et al., 2020; Sinaga et al., 2022). Nevertheless, many previous studies have measured motivation quantitatively without exploring the internal experiences that drive students' persistence and enthusiasm during project work (Zhao et al., 2021).

In analytical chemistry classes, entrepreneurial motivation is often strengthened through product exhibitions or sales of student-made items, such as soap, perfume, or cleaning products (Suryani et al., 2021). This experience reinforces students' confidence and sense of accomplishment, bridging cognitive learning with affective outcomes. Thus, PjBL not only improves conceptual understanding but also nurtures entrepreneurial motivation and creativity—two critical dimensions of vocational competence.

Teachers in vocational schools frequently encounter barriers such as limited equipment, materials, funding, and systemic support when implementing PjBL. Situmorang et al. (2018) reported that inadequate facilities are a major obstacle in implementing innovative chemistry teaching materials in secondary schools. Similarly, Herga et al. (2016) found that limited laboratory resources hinder students' conceptual understanding in science. Teachers often employ short-term strategies, such as using substitute materials or personal funds, but these are not sustainable (Anjarwati et al., 2016).

Beyond academic skills, vocational students are also expected to develop entrepreneurial motivation. According to Fayolle & Gailly (2015), entrepreneurship education fosters proactive, innovative, and risk-taking attitudes. Pujiyono et al. (2015) found that project-based learning, which produces tangible products, significantly enhances students' entrepreneurial interest, as they directly engage in both production and marketing processes.

From a theoretical perspective, the interrelation between PjBL, motivation, and creativity can be conceptualized as a dynamic framework. PjBL provides the learning environment, motivation serves as the driving force, and creativity emerges as the learning expression within authentic project experiences. This synthesis illustrates that meaningful vocational learning occurs when these three dimensions interact constructively (Aini et al., 2022; Deci & Ryan, 2017).

Nevertheless, a clear research gap remains. Few studies have deeply explored how chemistry teachers in vocational schools perceive and overcome pedagogical challenges while fostering students' motivation and creativity through project-based learning. Prior works have been predominantly quantitative or descriptive, providing limited insight into the teachers' subjective and contextual experiences. Therefore, a phenomenological qualitative approach is deemed appropriate to capture the *essence of teachers' lived experiences* in implementing PjBL within vocational analytical chemistry education (Creswell & Poth, 2018; Van Manen, 2021).

Nevertheless, school support remains limited, particularly in terms of financial assistance. As one teacher noted: *"The school supports us with the cooperative, so students can sell their products, but the capital provided is still very small."* This support is insufficient to ensure the sustainability of PjBL, leaving its implementation dependent on teachers' dedication. This aligns with the findings of Situmorang et al. (2018) and Anjarwati et al. (2016), which emphasized that resource and funding limitations are the main challenges in implementing innovative teaching in Vocational school.

Despite extensive studies on PjBL effectiveness, a research gap persists in understanding how teachers in chemistry vocational programs perceive and respond to challenges during its implementation. Prior works primarily adopt quantitative or descriptive designs, overlooking the teachers' subjective perspectives on sustaining motivation and creativity within resource-limited environments. Therefore, a phenomenological qualitative approach is justified to explore the *essence of teachers' lived experiences* in implementing PjBL for vocational analytical chemistry (Creswell & Poth, 2018; Van Manen, 2021).

In the context of Analytical Chemistry, entrepreneurial motivation grows when students can showcase or sell their project outcomes, such as soap, perfume, or cleaning products. Thus, PjBL not only enhances cognitive skills but also develops affective aspects, particularly students' motivation for entrepreneurship.

METHODS

This study employed a qualitative phenomenological design to explore the lived experiences of teachers and students in implementing Project-Based Learning (PjBL) within the *Analytical Chemistry* program at vocational high schools (SMK). The phenomenological approach was chosen because it provides a deep understanding of how participants interpret the challenges, motivation, and creativity that arise during project-based learning activities.

The research was conducted in several vocational schools located in the Malang–Batu region, East Java, Indonesia, which had adopted the *Kurikulum Merdeka* and integrated PjBL in the Analytical Chemistry expertise program. Participants consisted of four Analytical Chemistry teachers and one student group actively engaged in chemical product projects such as soap, perfume, and eco-enzyme. They were selected through purposive sampling based on the following criteria: (1) teachers who had implemented PjBL for at least two years, (2) students who had participated in at least one chemistry product project, and (3) schools that applied entrepreneurship-based learning.

Data were collected through semi-structured interviews, classroom observations, and documentation. Interviews were conducted individually with teachers and student groups using open-ended questions to explore their experiences, challenges, and strategies in implementing PjBL. Each session was recorded with participant consent. Observations focused on student engagement, teacher guidance, and laboratory project execution, while documentation included lesson plans, student project reports, and records from school cooperatives.

Data analysis followed the interactive model of Miles and Huberman (2014), which consists of three concurrent stages: (1) data reduction through coding and categorization of significant statements, (2) data display using thematic matrices to identify relationships among emerging themes, and (3) conclusion drawing and verification through continuous synthesis and comparison of findings.

To ensure the trustworthiness of the study, several validation strategies were implemented, including triangulation of interviews, observations, and documents; member checking to confirm the accuracy of interpretations; peer debriefing to minimize researcher bias; and maintaining an audit trail to ensure dependability. Rich contextual descriptions were provided to enhance transferability, and consistency in data analysis was maintained through systematic coding and memoing.

RESULT AND DISCUSSION

Challenges in Implementing Project-Based Learning

The implementation of Project-Based Learning (PjBL) in the Analytical Chemistry program at Vocational High Schools (SMK) revealed several interconnected challenges related to financial constraints, limited laboratory facilities, and curriculum structure. Teachers consistently reported that the financial support provided by schools was not adequate to meet the needs of laboratory-based projects. As a result, they often sought creative ways to obtain necessary materials, sometimes even using personal resources. This situation is consistent with Herga et al. (2016) and Widodo et al. (2020), who explained that inadequate resources are a persistent obstacle in vocational science education.

In addition to financial issues, limited laboratory facilities particularly the absence of advanced analytical instruments restricted students' opportunities to connect theory with practice. Teachers also indicated that some prerequisite subjects were taught after major project activities, resulting in students being less prepared to complete complex projects. This finding aligns with Krajcik and Blumenfeld (2006), who emphasized that coherent curriculum sequencing is a crucial element for the success of PjBL.

Teachers' Adaptive and Innovative Strategies

Despite the constraints, teachers demonstrated strong commitment and adaptability in maintaining the continuity of PjBL. They implemented various strategies to address limited materials and resources, such as utilizing locally available substances or modifying project designs to suit the school's conditions. These efforts represent what Anjarwati et al. (2016) describe as *pedagogical improvisation*, where teachers adjust instructional methods according to contextual limitations.

Teachers also actively engaged in professional development to strengthen their capacity in guiding students' projects. For example, some attended workshops or independent training programs related to product-based or creative industries. This initiative reflects the view of Bell (2010) that teacher competence plays a vital role in ensuring the success of project-based pedagogy.

Furthermore, teachers applied reflective monitoring techniques, including observation journals and video documentation, to track student participation and ensure accountability in the project process. This practice supports Lee and Blanchard's (2019) findings that reflective documentation enhances authentic assessment in PjBL and encourages students to engage more meaningfully in learning activities.

Students' Creativity and Problem-Solving Ability

From the students' perspective, involvement in PjBL encouraged the development of creativity, problem-solving, and innovation. Rather than being discouraged by limited materials, students used this as motivation to find alternative and eco-friendly resources to complete their projects. They experimented with various natural ingredients and locally available materials to create products such as personal care items, cleaning solutions, and eco-enzymes.

Students expressed satisfaction when their ideas succeeded, describing the process as both challenging and rewarding. This aligns with Rosello et al. (2018), who found that limited-resource environments stimulate divergent thinking and creativity among learners. The opportunity to independently develop new products encouraged students to take initiative, think critically, and apply their analytical chemistry knowledge in practical contexts.

Entrepreneurial Motivation through Authentic Learning Experiences

Student motivation significantly increased when they were allowed to showcase or sell their products through school exhibitions or cooperatives. These authentic learning experiences fostered a sense of pride, ownership, and entrepreneurial identity. Social recognition and economic appreciation served as strong motivators that reinforced students' commitment to learning. Fayolle and Gailly (2015) explain that such experiential learning promotes proactive attitudes, self-efficacy, and entrepreneurial interest in vocational students.

Through this process, students not only achieved cognitive learning outcomes but also developed affective and psychomotor competencies. Their engagement in production, packaging, and marketing reflected the integration of Higher Order Thinking Skills (HOTS) as described by Anderson and Krathwohl (2010), encompassing critical thinking, creativity, and reflection.

Institutional Support and Sustainability of PjBL

Although schools provided moral encouragement and limited logistical assistance, institutional support was still inadequate to sustain long-term PjBL implementation. Teachers highlighted the need for consistent funding, regular renewal of laboratory equipment, and structured collaboration with industries to enhance the practicality and sustainability of student projects. Situmorang et al. (2018) argue that systemic and institutional support is essential for ensuring the continuity of innovative chemistry learning.

Therefore, the success of PjBL should not rely solely on teacher dedication. Sustainable implementation requires coordinated efforts among schools, policymakers, and industry partners to ensure adequate resources, training, and guidance.

Synthesis of Findings

Overall, the study revealed that PjBL in vocational analytical chemistry effectively enhances creativity, critical thinking, and entrepreneurial motivation among students, even amid substantial challenges. Teachers acted as facilitators and adaptive agents who bridged limited resources with meaningful learning experiences, while students demonstrated innovation, responsibility, and resilience in overcoming obstacles.

These findings reaffirm the perspectives of Thomas (2000) and Bell (2010) that the success of project-based learning depends not only on pedagogical design but also on institutional commitment and resource support. Strengthening school–industry partnerships, integrating digital project-based modules, and providing continuous professional development for teachers are recommended strategies to ensure that PjBL continues to develop 21st-century competencies effectively.

CONCLUSION

Project-Based Learning (PjBL) in the Analytical Chemistry program effectively enhances students' creativity, critical thinking, and entrepreneurial motivation, despite various limitations in resources and infrastructure. Teachers acted as adaptive facilitators who creatively modified learning designs, used local materials, and applied reflective assessment to maintain project continuity. Students responded with innovative ideas and strong motivation to produce meaningful and marketable products.

However, the success of PjBL requires systemic and institutional support, including adequate funding, updated laboratory equipment, and collaboration with industries. Strengthening teacher professional development and integrating digital project-based modules can ensure the sustainability and effectiveness of PjBL implementation in vocational chemistry education.

In summary, PjBL serves as a relevant and transformative model for vocational learning bridging theory and practice while cultivating creative, critical, and entrepreneurial competencies essential for 21st-century graduates.

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