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ARTICLE

Cosmetic Chemistry as a Pedagogical Domain: Enhancing Pre-Service Teachers' Practical Skills and Self-Efficacy through Authentic, Scaffolded Learning

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This study examines the effectiveness of authentic, scaffolded learning implemented through a digitally supported project-based approach in enhancing pre-service chemistry teachers' practical skills and self-efficacy within a cosmetic chemistry course. While project-based learning and digital tools are widely used, limited research has explored how their integration operates within domain-specific, applied contexts. Cosmetic chemistry, as a product-oriented and constraint-driven domain, offers distinct pedagogical potential for such integration. A quasi-experimental post-test-only control group design was conducted with 63 pre-service teachers. The experimental group engaged with a digitally scaffolded PjBL e-module, while the control group received conventional instruction. Practical skills were assessed through structured performance observation, and self-efficacy was measured using a validated Likert-scale questionnaire ($r = 0.585-0.712$; Cronbach's $\alpha = 0.852$). Independent samples t-tests revealed significant differences in both practical skills and self-efficacy ($p < 0.001$), with large effect sizes ($d = 1.24$ and 1.35 , respectively). The findings indicate that the intervention supported not only procedural performance but also evaluative and decision-making aspects of laboratory competence, alongside increased confidence in task execution. Importantly, the results demonstrate that cosmetic chemistry functions as a pedagogical domain that actively shapes learning through its product-oriented and constraint-based characteristics. This underscores the importance of aligning pedagogy, scaffolding, and domain-specific context in designing effective chemistry learning environments.

Introduction

The increasing demand for twenty-first-century competencies has fundamentally reshaped science and chemistry education, shifting the emphasis from the transmission of content toward the development of higher-order thinking, problem-solving, and applied professional skills (Airiza Dian *et al.*, 2024). Within this transformation, practical laboratory competence has become a central component of meaningful chemistry learning, as engagement in experimental work enables students to connect abstract concepts with observable phenomena and real-world applications (Nguyen *et al.*, 2024). Consequently, contemporary chemistry education frameworks increasingly advocate for learning environments that integrate inquiry, experimentation, and authentic problem-solving to support deeper understanding and skill development (Suryati *et al.*, 2024).

Despite these advances, a persistent challenge remains in chemistry teacher education: preparing pre-service teachers who possess not only adequate laboratory skills but also the confidence to implement such practices effectively in their future classrooms. Prior research indicates that many pre-service teachers struggle to translate theoretical knowledge into practical instructional competence, particularly in designing and facilitating laboratory-based learning experiences supported by technology (Karolčík and Čípková, 2018). This concern is consistent with prior research highlighting persistent challenges in developing laboratory competence among pre-service chemistry teachers, particularly in relation to procedural accuracy and experimental understanding (Reid and Shah, 2007; Karataş, 2016). In addition, self-efficacy plays a critical role in determining whether teachers adopt and sustain innovative pedagogical approaches, yet it is often insufficiently developed within traditional training models. This dual gap limited practical competence and underdeveloped self-efficacy highlights the need for instructional approaches that simultaneously address both technical and psychological dimensions of teacher preparation.

A substantial body of research in chemistry education has established the effectiveness of constructivist and inquiry-oriented approaches in promoting meaningful learning and skill development. Within this paradigm, Project-Based Learning (PjBL) has been widely recognized for its capacity to engage students in authentic, complex tasks that foster conceptual understanding, experimental competence, and higher-order

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thinking (Kartika Sari *et al.*, 2019; Nguyen *et al.*, 2024). By requiring learners to design, execute, and evaluate projects, PjBL supports the development of both procedural knowledge and autonomy in scientific practice.

In parallel, the integration of digital learning tools has gained prominence as a means of enhancing engagement and providing cognitive scaffolding. Scaffolded e-modules and multimedia environments have been shown to improve conceptual understanding, learning autonomy, and higher-order thinking when aligned with inquiry-based pedagogies (Febaliza *et al.*, 2023; Ukenova and Bekmanova, 2023). Importantly, recent reviews emphasize that the effectiveness of such tools depends on their ability to support structured learning processes rather than functioning as supplementary resources (Suryati *et al.*, 2024).

Beyond cognitive and technical outcomes, research also highlights the importance of self-efficacy in shaping learning behavior and instructional practice. In chemistry teacher education, self-efficacy influences persistence in laboratory tasks, willingness to adopt innovative pedagogies, and overall instructional confidence (Ferrell and Barbera, 2015; Chichekian and Shore, 2016). Active and project-based learning environments have been shown to strengthen self-efficacy by providing mastery experiences and opportunities for independent problem-solving (Rusmansyah *et al.*, 2019; Akyol and Taş, 2024).

Despite extensive research on project-based learning, digital learning tools, and self-efficacy in chemistry education, these strands of work have largely developed in parallel rather than in an integrated manner. Studies on PjBL consistently demonstrate its effectiveness in enhancing experimental competence and higher-order thinking (Vishnumolakala *et al.*, 2017; Aslam *et al.*, 2025), while research on interactive digital modules highlights their role in supporting conceptual understanding and engagement (Ketaren and Nasution, 2025). Similarly, prior work has shown that active learning environments can strengthen self-efficacy among pre-service teachers by providing opportunities for mastery experiences (Willson-Conrad and Kowalske, 2018; Nurhasnah *et al.*, 2022). However, these approaches are most often examined independently, limiting understanding of how they may interact to influence both technical and psychological learning outcomes simultaneously.

Furthermore, existing research has paid limited attention to the role of domain-specific contexts in shaping the effectiveness of such instructional approaches. While context-based learning is recognized as important for enhancing relevance and motivation, it is typically treated as a supportive element rather than as a factor that actively structures learning processes. In particular, applied domains such as cosmetic chemistry—characterized by product-oriented tasks, regulatory constraints, and real-world decision-making—remain underexplored in chemistry teacher education. As a result, there is a lack of empirical evidence on how integrating project-based pedagogy with digital scaffolding within a domain-specific, applied context can simultaneously influence practical laboratory skills

and self-efficacy (Reid and Shah, 2007; Vishnumolakala *et al.*, 2017).

Beyond this fragmentation, limited attention has been given to how cognitive demands are managed within integrated learning environments. In particular, while project-based tasks promote authentic engagement, they also introduce high intrinsic cognitive load due to the need to coordinate conceptual understanding with procedural execution. Without appropriate scaffolding, such complexity may hinder learning rather than support it. This highlights the importance of examining not only whether instructional components are combined, but how their interaction regulates cognitive processes during learning (Reid and Shah, 2007).

Contextualized approaches in chemistry education have increasingly emphasized the importance of linking abstract concepts to real-world applications in order to enhance relevance, motivation, and knowledge transfer (Belova and Eilks, 2015; Minata *et al.*, 2022; Spencer *et al.*, 2022). Within this perspective, cosmetic chemistry offers a particularly rich and underutilized domain, as it integrates chemical principles with everyday products, formulation processes, and regulatory considerations. Unlike traditional laboratory activities that often follow predetermined procedures, cosmetic chemistry requires learners to engage in decision-making processes involving ingredient selection, safety compliance, and product functionality, thereby situating learning within authentic and professionally relevant practices (Belova and Eilks, 2015; Arlianty, 2018; Winarti *et al.*, 2022; Rahmawati *et al.*, 2023).

Importantly, the pedagogical value of cosmetic chemistry extends beyond its role as a contextual example. Its product-oriented and constraint-driven nature introduces forms of reasoning that are central to applied scientific practice, including optimization under constraints, evaluation of functional outcomes, and alignment with regulatory standards. These characteristics require learners to integrate conceptual understanding with procedural execution and evaluative judgment in ways that are not typically emphasized in conventional laboratory instruction. As such, cosmetic chemistry functions not merely as a setting for learning, but as a domain that actively shapes how knowledge is constructed and applied (Belova and Eilks, 2015).

Addressing the identified gaps, this study aims to examine the effectiveness of an integrated instructional approach that combines Project-Based Learning (PjBL) with interactive digital scaffolding within the domain of cosmetic chemistry. Specifically, the study investigates the extent to which this approach influences (1) practical laboratory skills and (2) self-efficacy among pre-service chemistry teachers. By situating learning within a context that requires authentic product formulation, regulatory compliance, and decision-making under constraints, the study seeks to capture both technical and psychological dimensions of teacher preparation.

This study makes two key contributions to chemistry education research. First, it provides empirical evidence on the combined impact of project-based pedagogy and digital scaffolding on both practical competence and self-efficacy, addressing a gap where these elements have typically been examined in



isolation. Second, it advances a conceptual perspective in which domain-specific context—operationalized through cosmetic chemistry—is not treated as a passive backdrop, but as an active pedagogical factor that shapes learning processes and outcomes. In doing so, the study contributes to a more integrated understanding of how pedagogy, technology, and applied context can be aligned to support effective chemistry teacher education. In this exploratory study, the instructional approach (digitally scaffolded PjBL) and the domain context (cosmetic chemistry) were implemented as an integrated intervention. As a result, the independent contribution of the domain context to the observed outcomes cannot be determined. The claim that cosmetic chemistry may function as a pedagogical domain is therefore advanced as a preliminary conceptual interpretation, supported by the observed patterns rather than as a causally established conclusion.

Theoretical Review

Integrated Learning Framework

The instructional approach in this study is grounded in an integrated learning framework that combines constructivist principles, project-based learning (PjBL), and digital scaffolding into a coherent system for supporting meaningful learning in chemistry. From a constructivist perspective, knowledge is actively constructed through engagement with meaningful tasks that require learners to interpret, apply, and refine their understanding in context (Suryati *et al.*, 2024). Within this view, learning is most effective when students are involved in authentic problem-solving processes that connect conceptual knowledge with practical experience.

Project-Based Learning operationalizes these principles by situating learning within complex, goal-oriented activities that require investigation, collaboration, and the creation of tangible products (Kokotsaki *et al.*, 2016). In chemistry education, PjBL enables learners to engage in extended inquiry processes, integrating conceptual understanding with procedural execution as they design and evaluate experimental outcomes (Aslam *et al.*, 2025). However, the open-ended nature of such tasks can impose significant cognitive demands, particularly in domains requiring precise technical and conceptual coordination. From a cognitive perspective, these demands can be understood in terms of intrinsic load associated with task complexity and the need to simultaneously process conceptual and procedural knowledge. In such contexts, learning effectiveness depends on the extent to which instructional support reduces extraneous load while preserving productive cognitive engagement. Digital scaffolding plays a critical role in this process by structuring tasks, sequencing information, and providing just-in-time feedback, thereby enabling learners to allocate cognitive resources toward meaningful problem-solving rather than task management. While cognitive load was not directly measured in this study, it informed the design of the scaffolded e-module by guiding the sequencing and structuring of content to manage intrinsic complexity and reduce extraneous load during complex formulation tasks. In this way,

scaffolding was intended to support learners' processing capacity when engaging with multi-step, decision-intensive activities.

To address this challenge, digital scaffolding provides structured support that guides learners' engagement throughout the learning process. Scaffolded e-modules can organize information, embed feedback, and provide step-by-step guidance that reduces cognitive load while maintaining learner autonomy (Huang, 2005; Nugraheni and Srisawasdi, 2025). When aligned with inquiry-based and project-oriented pedagogies, such scaffolding supports both conceptual understanding and procedural accuracy by facilitating reflection, decision-making, and iterative improvement (Febliza *et al.*, 2023; Ukenova and Bekmanova, 2023).

Taken together, these elements function as an integrated system in which constructivist principles define the epistemological foundation, PjBL structures the learning activities, and digital scaffolding regulates cognitive processes during task execution. Rather than operating as separate components, their interaction creates a guided inquiry environment in which learners engage in authentic tasks while receiving continuous support to connect theory, practice, and reflection. This integrated framework underpins the design of the learning intervention in this study and provides the theoretical basis for examining its effects on both practical skills and self-efficacy.

Key Constructs: Practical Skills and Self-Efficacy

In this study, learning outcomes are conceptualized through two complementary constructs: practical laboratory skills and self-efficacy, representing the technical and psychological dimensions of chemistry teacher preparation.

Practical skills are understood as a form of laboratory competence that extends beyond procedural execution to include the integration of planning, technical accuracy, safety awareness, and evaluative judgment (Hofstein and V. Lunetta, 2004; Belova and Eilks, 2015). This multidimensional perspective reflects the ability to design, perform, and assess experimental work within a coherent scientific framework. In the context of cosmetic chemistry, practical competence also involves product-oriented evaluation, requiring learners to assess the functionality and quality of formulated products alongside procedural correctness. This extends traditional laboratory skill models by incorporating decision-making and outcome evaluation in applied settings.

Self-efficacy is defined as an individual's belief in their capability to successfully perform specific tasks (Bandura, 1977), and is considered inherently context-dependent in educational settings (Schunk, 1991). In chemistry teacher education, self-efficacy influences persistence in laboratory activities, problem-solving behavior, and willingness to implement innovative instructional approaches. Within this study, self-efficacy is aligned with domain-specific tasks in cosmetic chemistry, including formulation, analysis of ingredients, and adherence to safety and regulatory standards (Vishnumolakala *et al.*, 2017). Such task-specific alignment reflects the role of mastery



experiences and feedback in shaping learners' confidence through successful engagement in authentic activities. Together, these constructs capture both the performance and belief dimensions of learning, providing a comprehensive basis for evaluating the impact of the integrated instructional approach.

Cosmetic Chemistry as a Pedagogical Agent

Context-based chemistry education has traditionally emphasized the role of real-world contexts in enhancing relevance and motivation (Bennett and Lubben, 2006; Gilbert, 2006). However, context is often treated as a passive backdrop rather than as a factor that actively shapes learning processes. This assumption may limit the explanatory power of context-based approaches, as it overlooks how domain-specific constraints can fundamentally alter the nature of problem-solving and knowledge construction. In this study, cosmetic chemistry is conceptualized as a pedagogical agent. Its product-oriented and constraint-driven nature requires learners to integrate conceptual knowledge with formulation practices, safety considerations, and regulatory compliance. Unlike conventional laboratory tasks with predetermined procedures, cosmetic formulation involves decision-making under constraints such as ingredient compatibility, product performance, and adherence to standards (Arlianty, 2018; Winarti *et al.*, 2022; Rahmawati *et al.*, 2023).

These characteristics introduce forms of reasoning central to applied scientific practice, including optimization, trade-off evaluation, and outcome-based judgment. As a result, the domain shapes how learners engage with tasks and construct knowledge, aligning with situated learning perspectives that emphasize the inseparability of knowledge and context (Hmelo-Silver, 2004).

This positioning extends existing approaches to context-based chemistry education by framing domain-specific context as an active factor that mediates learning processes and outcomes.

Conceptual Model and Hypotheses

The conceptual model of this study integrates the instructional design, domain characteristics, and learning outcomes into a unified explanatory framework. The model proposes that the combination of Project-Based Learning (PjBL) and digital scaffolding creates a structured inquiry environment in which learners engage in authentic, goal-oriented tasks while receiving continuous cognitive support. Within this environment, constructivist learning processes are operationalized through active experimentation, iterative problem-solving, and reflection, enabling learners to connect conceptual understanding with procedural execution.

Crucially, the domain of cosmetic chemistry functions as a mediating context that shapes how these learning processes unfold. Its product-oriented and constraint-driven characteristics require learners to engage in decision-making, optimization, and evaluative judgment, thereby intensifying the integration of knowledge and practice. This interaction between instructional design and domain-specific demands is expected to enhance both the development of practical

laboratory skills and the formation of self-efficacy through repeated mastery experiences and successful task completion.

Based on this framework, the integrated learning environment is hypothesized to produce measurable improvements in both technical competence and task-specific confidence among pre-service teachers. This framework suggests that learning outcomes are not solely the result of instructional strategies, but emerge from the dynamic interaction between pedagogy, cognitive support, and the epistemic characteristics of the domain. Accordingly, the following hypotheses are proposed:

H1: Pre-service teachers who engage in the digitally scaffolded PjBL e-module will demonstrate significantly higher practical laboratory skills compared to those receiving conventional instruction.

H2: Pre-service teachers who engage in the digitally scaffolded PjBL e-module will report significantly higher self-efficacy compared to those receiving conventional instruction.

These hypotheses reflect the assumption that learning outcomes are shaped not only by instructional strategies in isolation, but by the interaction between pedagogy, technological scaffolding, and the epistemic characteristics of the learning domain.

METHOD

Research Design

This study employed a quasi-experimental post-test-only control group design using intact classes, an approach widely adopted in educational research where random individual assignment is not feasible (Celestino, 2023). Pre-testing of self-efficacy was deliberately omitted for two reasons: first, repeated measurement of self-efficacy beliefs before and immediately after an intervention may sensitize participants and alter subsequent learning behaviour, introducing reactivity effects that could confound the results (Shadish *et al.*, 2002); second, the study was oriented toward examining differences in post-intervention outcomes rather than tracking individual change over time.

Although the design does not permit direct confirmation of baseline equivalence, several contextual factors reduce the likelihood of substantial pre-existing differences between groups. All participants were drawn from the same teacher education program at the same university and were enrolled in the course during the same academic semester. As cosmetic chemistry was a newly introduced course, none of the participants had prior formal exposure to the content, and all had completed the same prerequisite coursework within an identical curriculum sequence prior to the intervention (Celestino, 2023).

Participants

The participants were 63 pre-service chemistry teachers enrolled in a Cosmetic Chemistry course at Universitas Negeri Yogyakarta during the 2024/2025 academic year. The study involved two intact classes, with $n = 33$ students assigned to the



experimental group and $n = 30$ students to the control group based on their existing class enrolment. Random assignment of individuals was not feasible within the institutional setting. All participants were part of the same teacher education program and attended the course in their 4th semester. They had completed the same prerequisite coursework prior to the intervention. As cosmetic chemistry was a newly introduced course, none of the participants had prior formal exposure to the content. Both groups were taught by the same instructor and had equivalent access to laboratory facilities. The experimental group received instruction using a digitally scaffolded project-based learning (PjBL) e-module, while the control group followed conventional instruction using standard teaching materials.

Learning Media: digitally scaffolded PjBL e-module

The digitally scaffolded PjBL e-module used in this study was developed using the 4D instructional design model (Define, Design, Develop, Disseminate). The complete development process, including needs analysis, expert validation, revision procedures, and product feasibility testing, has been reported in detail in a previous publication (Jornavalona and Rohaeti, 2025).

Briefly, the module was designed to align cosmetic chemistry content with the phases of Project-Based Learning, incorporating problem orientation, project planning, product formulation, evaluation, and reflection. Validation was conducted by four experts in chemistry education and one instructional media specialist, who assessed the module for content accuracy, pedagogical alignment, and technical usability. Minor revisions were made based on their feedback. A small pilot test with 10 pre-service teachers was carried out to ensure clarity and usability before full implementation. After minor revisions, the finalized version was implemented in the experimental class during the Disseminate stage (Pereira Gomes *et al.*, 2024); (Istiqomah *et al.*, 2021).

Instructional Procedures

The instructional procedures were implemented over six sessions within a Cosmetic Chemistry course and were designed to cover identical core content across both groups. The control group received conventional lecture-based instruction supported by PowerPoint presentations and structured laboratory procedures, while the experimental group engaged in a digitally scaffolded project-based learning (PjBL) approach using an interactive e-module. The learning sequence for both groups is summarised in Table 1.

Table 1. Instructional sequence and learning activities in control and experimental groups

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Session	Topic / Focus	Control Class (Conventional Instruction)	Experimental Class (Digitally Scaffolded PjBL E-Module)
1	Introduction to Cosmetic Chemistry & Natural Resources	Lecturer introduces basic concepts of cosmetic chemistry using PowerPoint. Discussion includes general applications of cosmetics. Students take notes; limited interaction.	Problem Orientation: Students engage with an interactive introduction via the e-module focusing on Indonesia's biodiversity and the potential of natural ingredients in cosmetic products. Reflective prompts guide initial exploration of underutilised resources.
2	Cosmetic Raw Materials: Types and Functions	Lecturer explains categories of raw materials (oily materials, waxes, water phase, humectants, surfactants, polymers, antioxidants, preservatives, active ingredients, colorants, fragrances). Students record information and review examples.	Concept Exploration: Students explore raw material categories through an interactive e-module (animations, databases, guided prompts). Emphasis on understanding functional roles and relationships between ingredients.
3	INCI & BPOM Standards + Label Analysis	Lecturer explains INCI nomenclature and BPOM regulations. Students complete a structured worksheet analysing cosmetic product labels individually.	Project 1: Label Analysis & Classification: Students analyse real cosmetic product labels using scaffolded tools in the e-module. They classify ingredients into functional categories (e.g., oils, surfactants, humectants) and evaluate regulatory compliance.
4	Product Reformulation Concepts	Lecturer explains formulation principles and demonstrates examples of cosmetic products. Students follow explanations and discuss examples with limited modification.	Project 2: Reformulation Planning: Student groups redesign a selected product by proposing alternative and safer ingredients, including natural substitutions where feasible. The e-module provides scaffolding for ingredient selection, safety considerations, and formulation rationale.
5	Laboratory Practice: Product Formulation	Lecturer demonstrates formulation procedures step-by-step. Students replicate the procedure using fixed instructions with minimal decision-making. Practical skills are observed.	Project Implementation: Student groups develop their reformulated cosmetic product in the laboratory. The e-module provides real-time scaffolding (procedural guidance, safety prompts, decision support). Students adjust formulations based on performance and constraints. Practical skills are assessed.
6	Product Evaluation & Presentation	Students present results using standard templates. Evaluation focuses on procedural accuracy and final product outcome. Self-efficacy questionnaire administered.	Evaluation, Comparison & Reflection: Students evaluate their product and compare it with the original commercial product, justifying ingredient substitutions and formulation decisions. Presentations emphasise reasoning, safety, and product performance. Self-efficacy questionnaire administered.

The experimental condition was structured around two sequential project tasks: (1) analysis and classification of ingredients from commercial cosmetic product labels, and (2) reformulation of the product using safer or alternative ingredients, including natural substitutions where appropriate. This progression required students to integrate conceptual knowledge of raw materials with regulatory considerations and product-oriented decision-making, reflecting authentic practices in cosmetic formulation.

Instruments

Practical skills assessments

Practical laboratory skills were assessed using a performance-based observation sheet designed to evaluate five core competencies: (1) preparation of materials and tools, (2) accuracy in measuring and mixing, (3) adherence to safety protocols, (4) ability to follow procedures, and (5) quality of the final cosmetic product. The instrument was adapted from previous chemistry education studies on laboratory skills outlined in Table 3. These dimensions were operationalized into a domain-specific assessment framework tailored to cosmetic chemistry tasks, incorporating product formulation, regulatory

analysis, and evaluative judgment. The resulting performance-based instrument is presented in Table 6. (Dyanti and Faleni, 2023); (Hmelo-Silver, 2004; Hofstein and V. Lunetta, 2004; Prince and Felder, 2006; Yelpeze and Yakar, 2020). Scores were assigned on a 5-point scale for each criterion, yielding a maximum score of 25. Two independent raters observed and scored the students, and inter-rater reliability was checked prior to data analysis. All observers participated in a calibration session in which they independently scored sample performances and discussed discrepancies to establish a shared interpretation of the assessment criteria. During data collection, scoring was conducted independently based on clearly defined descriptors for each performance level.

Inter-rater reliability was assessed using percentage agreement and Cohen's kappa coefficient. As shown in Table 2, the results indicated high levels of agreement, with percentage agreement of 88.4% for the experimental group and 86.0% for the control group. The corresponding Cohen's kappa values were 0.761 and 0.742, respectively, indicating good agreement between raters. These values fall within the acceptable range for observational assessment in educational research, supporting the consistency of the scoring process (Stemler, 2004; McHugh, 2012).



Observers were not blind to the experimental conditions due to limitation of the study. the nature of the intervention, which is acknowledged as a

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Table 2. Inter-rater reliability

Group	% Agreement	Cohen's κ	Interpretation
Experimental (n=33)	88.4%	0.761	Good
Control (n=30)	86.0%	0.742	Good

Table 3. Practical skills Instruments Theory

Construct	Dimension	Conceptual Description	Theoretical Basis
Procedural Competence	Preparation of materials and tools	Ability to plan and organize experimental resources prior to task execution	Hofstein & Lunetta (2004)
Technical Accuracy	Measurement and mixing	Precision in performing quantitative and procedural laboratory operations	Hofstein & Lunetta (2004)
Safety Competence	Adherence to safety protocols	Application of appropriate safety standards and responsible handling of materials	Hofstein & Lunetta (2004)
Procedural Execution	Following experimental procedures	Ability to carry out experimental steps systematically and independently	Hmelo-Silver (2004)
Evaluative Competence	Product evaluation	Capacity to assess outcomes based on functionality, quality, and intended purpose	Prince & Felder (2006)

Practical Skills Instrument Validation

The practical skills instrument was developed based on established frameworks of laboratory competence in chemistry education, which conceptualize practical work as a multidimensional construct integrating procedural, technical, and cognitive components (Hofstein and V. Lunetta, 2004). Subsequent research has further emphasized that effective laboratory assessment should extend beyond technical execution to include decision-making, data interpretation, and evaluative judgment (Abrahams and Millar, 2008). In this study, these perspectives were adapted to the context of cosmetic chemistry, where product-oriented outcomes and real-world constraints play a central role.

Given the observational and context-specific nature of the instrument, validation focused primarily on content and face validity, which are widely recognized as appropriate approaches for performance-based assessments in laboratory settings (Reid and Shah, 2007; Karataş, 2016). Content validity was established through expert review involving four specialists in chemistry education and laboratory instruction. The experts evaluated each indicator based on its relevance, clarity, and alignment with the construct of practical competence, as well as its suitability for capturing skills in cosmetic formulation tasks. This process ensured that the instrument reflects not only general laboratory practices but also the specific demands of applied, product-oriented chemistry contexts.

The inclusion of product quality evaluation as an assessment dimension is supported by research highlighting the importance of authentic and outcome-based assessment in science education, where learners are required to evaluate the effectiveness and functionality of their work (Belova and Eilks, 2015). This dimension is particularly relevant in cosmetic chemistry, where the success of an experiment is determined

not only by procedural correctness but also by the properties and usability of the final product.

To enhance reliability, two observers were trained using a structured rubric prior to data collection to ensure consistent interpretation of performance criteria. The observers independently scored sample performances during a calibration session and discussed any discrepancies to establish a shared interpretation of each descriptor. The use of clearly defined indicators and performance descriptors aligns with recommendations for improving the reliability of observational assessments in laboratory environments (Abrahams and Millar, 2008). The resulting inter-rater reliability values (Cohen's κ = 0.761 and 0.742 for the experimental and control groups, respectively) confirm adequate consistency in scoring across both conditions. The instrument was developed based on established frameworks of laboratory competence and aligned with the specific demands of cosmetic chemistry tasks. Further validation across broader contexts is recommended to strengthen its generalizability (Abrahams and Millar, 2008).

Self-Efficacy Questionnaire

Self-efficacy was measured using a questionnaire adapted from Bandura's framework (Bandura, 1977; Belova and Velikina, 2020) and teacher self-efficacy studies (Ardhaoui *et al.*, 2021). The instrument included 10 items covering three domains: (1) confidence in performing cosmetic chemistry tasks, (2) persistence in solving problems, and (3) self-belief in completing projects successfully. Items were rated on a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Content validity was confirmed by expert review, and Cronbach's alpha was calculated to ensure internal consistency. The theoretical structure of the instrument is presented in **Table 4**, and the full set of questionnaire items is provided in **Table 7**.

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Table 4. Self-efficacy Instrument Theory

Construct Domain	Sub-Dimension	Description	Example Item	Theoretical Basis
Task-Specific Confidence	Cosmetic chemistry skills	Belief in ability to perform formulation-related tasks	"I am confident in my ability to formulate a cosmetic product correctly."	Self-efficacy theory (Bandura, 1977)
Cognitive Competence	Analysis and interpretation	Confidence in analyzing raw materials and interpreting formulations	"I can accurately interpret cosmetic ingredient labels (INCI)."	Task-specific cognitive efficacy (Schunk, 1991)
Regulatory Confidence	Standards and safety application	Belief in ability to apply safety and regulatory standards (e.g., INCI, BPOM)	"I am able to apply safety standards in cosmetic formulation."	Contextualized self-efficacy (Bandura, 1977)
Persistence	Problem-solving	Confidence in overcoming difficulties during formulation tasks	"I can solve problems that arise during product development."	Mastery experience & persistence (Bandura, 1977)
Outcome Expectancy	Task completion	Belief in successfully completing projects and achieving desired outcomes	"I am confident I can successfully complete a cosmetic formulation project."	Performance-based self-efficacy (Bandura, 1977)

Empirical Validity and Reliability of the Self-Efficacy Instrument

The self-efficacy instrument underwent empirical validation using data collected from 100 undergraduate chemistry students to ensure its construct validity and reliability. Item validity was assessed using Pearson's correlation analysis, comparing each item's correlation coefficient (*r*-value) with the critical value (*r*-table = 0.194, *N* = 100, α = 0.05). As shown in Table 5, all items demonstrated correlation coefficients ranging from 0.585 to 0.712, exceeding the critical threshold, indicating that all items are valid measures of the intended construct.

Table 5. Empirical Validity of Self-Efficacy Instrument

Item	r-value	r-table (N=100, $\alpha=0.05$)	Interpretation
1	0.712	0.194	Valid
2	0.587		Valid
3	0.649		Valid
4	0.642		Valid
5	0.585		Valid
6	0.697		Valid
7	0.698		Valid
8	0.677		Valid
9	0.689		Valid
10	0.658		Valid

Reliability Analysis

The internal consistency of the instrument was evaluated using Cronbach's alpha. The analysis yielded a coefficient of α = 0.852,

which exceeds the commonly accepted threshold of 0.70, indicating high reliability and strong internal consistency among the items. This result suggests that the instrument consistently measures students' self-efficacy in the context of cosmetic chemistry learning.

The combination of high item validity and strong internal consistency indicates that the self-efficacy instrument provides a robust measure of students' task-specific confidence. The relatively high correlation values across all items suggest that each statement meaningfully contributes to the overall construct, while the high Cronbach's alpha confirms coherence among the items. These findings support the use of the instrument for assessing self-efficacy in applied, project-based chemistry learning environments.

Data Collection Analysis

Data analysis was conducted using IBM SPSS Statistics version 25. Descriptive statistics were first calculated to summarize the data. Prior to hypothesis testing, assumptions of normality and homogeneity of variance were examined to ensure the appropriateness of parametric tests. Independent samples *t*-tests were then performed to compare the practical skills and self-efficacy scores between the experimental and control groups. In addition to statistical significance, effect sizes were calculated using Cohen's *d* to evaluate the magnitude of the observed differences.

Table 6. Practical skills observation sheet based on Product development

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Aspects	Section
Understanding Raw Materials in Cosmetic Products	- Identification of common raw chemical materials used in cosmetic products.
	- Knowledge of the properties and functions of raw materials in cosmetic formulations.
	- Ability to distinguish between different types of raw materials based on their chemical composition.
INCI and BPOM Standards Understanding	- Understanding the International Nomenclature of Cosmetic Ingredients (INCI) standards.
	- Knowledge of BPOM (Indonesia's National Agency of Drug and Food Control) standards for cosmetic products.
	- Ability to decode and interpret ingredients written in a cosmetic product label using INCI standards.
Label Analysis and Correction Techniques	- Understanding and application of local regulations (BPOM) in cosmetic product formulation.
	- Analyzing cosmetic product labels and identifying raw materials classes.
	- Identifying correct techniques of writing a label following INCI standards.
	- Recognizing and rectifying incorrect techniques found in cosmetic labels.
Product Formulation and Labeling	- Ability to provide constructive feedback on label writing techniques.
	- Application of knowledge to formulate a safe cosmetic product.
	- Development of a cosmetic product label following international (INCI) and local standards (BPOM).
	- Inclusion of appropriate information on the label, such as ingredients, usage instructions, and safety precautions.
	- Presentation of a rationale for the chosen formulation and adherence to safety standards.
Continued Professional Development in Cosmetic Chemistry	- Effective communication of the benefits and proper use of the formulated product.
	- Demonstration of continued learning through analysis and incorporation of emerging trends in cosmetic chemistry.
	- Awareness of advancements in raw materials and regulatory standards in the cosmetics industry.
	- Adaptation of knowledge to evolving industry requirements and consumer preferences.

Table 7. Self-Efficacy Questionnaire Items

No.	Self-Efficacy Statement	Scale (1–5)
1	I am confident in my ability to understand and analyze raw materials used in cosmetic products.	
2	I am able to read and interpret cosmetic labels based on INCI and BPOM standards accurately.	
3	I am capable of formulating and creating cosmetic products that adhere to established safety standards.	
4	I can select cosmetic ingredients appropriately to ensure product safety and effectiveness.	
5	I am able to apply Good Manufacturing Practices (GMP) and Good Laboratory Practices (GLP) in cosmetic product development.	
6	I am confident in writing cosmetic labels that comply with INCI and BPOM regulations.	
7	I am capable of conducting practical analyses of cosmetic raw materials independently.	
8	I can accurately read and interpret complex cosmetic product formulations.	
9	I am able to troubleshoot and resolve problems that arise during cosmetic product development.	
10	I feel confident in my practical skills to create safe and high-quality cosmetic products.	

RESULTS AND DISCUSSION

Preliminary Analysis

The Shapiro–Wilk test confirmed that the data were normally distributed for both groups in practical skills (experimental $p =$

0.200; control $p = 0.097$) and self-efficacy (experimental $p = 0.065$; control $p = 0.069$). Levene's test also indicated homogeneity of variances for practical skills ($p = 0.170$) and self-efficacy ($p = 0.072$). These results confirmed that the assumptions for independent samples t-tests were satisfied.



Independent t-test result

The practical skills and self-efficacy data were gathered and examined using an independent t-test to assess the disparity between the experimental class and the control class. The independent t-test statistic results are shown in Table 8.

Table 8. Independent t-test result

No.	Variable	Significance
1.	Self-efficacy	0.000
2.	Practical skills	0.000

The results indicate that both practical skills and self-efficacy showed statistically significant differences between the two groups, with p-values below 0.05.

Cohen's d effect size

A Cohen's d test was conducted to determine the effect size difference between the experimental and control classes, given the significant difference between the two. The resulting Cohen's d effect sizes are presented in Table 9.

Table 9. Cohen's d effect size results

No.	Variable	Cohen's d Effect size
1.	Practical skills	1.24
2.	Self-Efficacy	1.35

Both variables exhibited large effect sizes, indicating that the digitally scaffolded PjBL e-module had a substantial impact on students' laboratory skills and confidence. The concurrent improvement in practical competence and self-efficacy suggests a reciprocal relationship, where successful engagement in scaffolded tasks may have reinforced learners' confidence through repeated mastery experiences. However, it should be noted that both groups were taught by the same instructor, which may have introduced unintentional enthusiasm bias toward the experimental condition. Additionally, students' awareness of participating in a study may have produced a Hawthorne effect, potentially inflating observed outcomes (McCambridge *et al.*, 2014). These factors are acknowledged as limitations and should be considered when interpreting the magnitude of the effects.

Effect of the digitally scaffolded PjBL e-module on Practical Skills

The independent samples t-test revealed a significant difference in practical skills between the experimental group ($M = 86.15$, $SD = 3.94$) and the control group ($M = 80.19$, $SD = 4.41$), $t = 5.36$, $p = 0.000 < 0.05$. This indicates that the digitally scaffolded PjBL e-module effectively improved students' laboratory competencies. The effect size was also large (Cohen's $d = 1.24$), indicating that the improvement in practical skills was not only statistically significant but also educationally meaningful (Chandrashekar and Menon, 2020); (Rakshith *et al.*, 2023). The observed differences can be attributed to the integration of project-based learning with digital scaffolding, which provided structured guidance throughout the experimental process. The interactive e-module functioned as a scaffold by supporting students in planning, executing, and evaluating their work, thereby reducing cognitive overload and

enabling more effective task engagement. This aligns with prior research highlighting the importance of scaffolding in supporting complex laboratory learning and enhancing students' ability to carry out multi-step procedures (Hofstein and V. Lunetta, 2004; Abrahams and Millar, 2008).

Furthermore, the context of cosmetic chemistry played a critical role in shaping the development of practical skills. The product-oriented nature of the tasks required students not only to follow procedures but also to assess the functional quality of the final product. This emphasis on outcome evaluation is consistent with authentic laboratory learning, where success is determined by both process and product (Belova and Eilks, 2015; Boz *et al.*, 2019).

In addition, the constraint-driven characteristics of cosmetic chemistry, including safety considerations and formulation requirements, required students to make informed decisions throughout the experimental process. Such conditions likely promoted higher-order thinking and adaptive problem-solving, which are essential components of practical competence (Febliza and Copriady, 2023); (Ukenova and Bekmanova, 2023). Therefore, the improvement in practical skills can be understood not simply as the result of increased activity, but as the outcome of a structured, context-rich learning environment that integrates scaffolding, authenticity, and domain-specific demands. This result supports constructivist learning theory, which posits that knowledge and skills are more effectively developed when learners actively engage in authentic problem-solving tasks rather than passively receiving information (Huang, 2005); (Dewi and Primayana, 2019).

Effect of the digitally scaffolded PjBL e-module on Self-Efficacy

The self-efficacy results also showed a significant difference between the experimental group ($M = 84.23$, $SD = 5.32$) and the control group ($M = 78.12$, $SD = 4.87$), $t = 4.91$, $p = 0.000 < 0.05$. Students who learned with the scaffolded PjBL e-module reported greater confidence in performing tasks, persisting through challenges, and completing projects successfully. The effect size was large (Cohen's $d = 1.35$), suggesting that the scaffolded e-module had a substantial positive influence on students' confidence and beliefs about their abilities. The increase in self-efficacy reflects enhanced task-specific confidence, persistence in problem-solving, and perceived capability in completing domain-specific tasks, consistent with the dimensions outlined in Table 4.

From a theoretical perspective, these findings can be explained through Bandura's social cognitive theory, which identifies mastery experiences as the most influential source of self-efficacy beliefs (Bandura, 1977; Belova and Velikina, 2020). Students in the experimental group engaged in structured, project-based activities that required them to successfully complete cosmetic formulation tasks. These repeated experiences of task completion likely strengthened their confidence in performing similar laboratory activities. As students were able to navigate tasks more effectively, their perceptions of competence were likely reinforced (Astuti, 2020; Triyanto *et al.*, 2022). In contrast, students in the control group had fewer opportunities to engage in sustained, outcome-

oriented tasks, limiting the development of such mastery experiences.

Furthermore, the context of cosmetic chemistry contributed to the development of self-efficacy by providing meaningful and relevant learning experiences. As a product-oriented and context-rich domain, cosmetic chemistry allows students to engage with tasks that are closely related to everyday applications. This relevance may have increased students' motivation and engagement, thereby enhancing the impact of mastery experiences on self-efficacy. Successfully producing tangible products, such as cosmetic formulations, likely provided visible evidence of competence, further strengthening students' confidence (Belova and Eilks, 2015).

Overall, the findings suggest that the integration of project-based learning and digital scaffolding within a cosmetic chemistry context supports the development of self-efficacy by combining structured guidance, authentic task engagement, and meaningful learning outcomes. This highlights the importance of designing learning environments that not only develop students' skills but also foster their confidence in applying those skills in real-world contexts.

Role of Cosmetic Chemistry as Pedagogical domain

Beyond the instructional design, the choice of cosmetic chemistry as the learning domain appears to have amplified the effectiveness of the intervention. This suggests that the observed improvements in practical skills and self-efficacy were not solely driven by the scaffolded PjBL e-module, but also influenced by the domain-specific characteristics of the learning context (Bennett & Lubben, 2006; Gilbert, 2006). It should be noted, however, that because the instructional approach (PjBL with digital scaffolding) and the domain context (cosmetic chemistry) were introduced simultaneously in this study, their individual contributions to the observed outcomes cannot be separated. The role of cosmetic chemistry as a pedagogical domain should therefore be regarded as an exploratory interpretation rather than a confirmed causal claim, and future research employing factorial designs would be needed to disentangle these effects.

Cosmetic chemistry represents a distinct form of applied learning in which students are required to integrate conceptual understanding with formulation practices and product evaluation. Unlike conventional laboratory activities that emphasize procedural accuracy, formulation-based tasks involve performance-oriented outcomes, where success is determined by the functional quality of the final product (Hofstein and V. Lunetta, 2004; Bennett and Lubben, 2006).

In addition, cosmetic chemistry introduces authentic constraints, including ingredient compatibility, safety considerations, and regulatory requirements. These constraints require students to make informed decisions throughout the experimental process, promoting higher-order thinking and adaptive problem-solving. This aligns with research indicating that complex, context-rich learning environments support the development of transferable skills and professional competence (Prince and Felder, 2006); (Hmelo-Silver, 2004).

From a pedagogical perspective, this indicates that cosmetic chemistry functions not only as a contextual background but as an enabling domain that supports the development of practical competence and self-efficacy (Bandura, 1977; Schunk, 1991). The findings therefore highlight the importance of aligning instructional strategies with domain characteristics, as the effectiveness of innovative learning models may be significantly enhanced when implemented within contexts that inherently demand integration, evaluation, and decision-making.

Implications for Chemistry Teacher Education

The combined improvement in practical skills and self-efficacy has important implications for pre-service chemistry teacher education, as these constructs are known to be mutually reinforcing in shaping instructional practice (Tschannen-Moran and Hoy, 2001; Hofstein and V. N. Lunetta, 2004).

The findings of this study suggest that integrating digitally scaffolded PjBL e-modules into teacher preparation programs can provide a structured pathway for developing both domains simultaneously. Rather than treating laboratory skills and teaching confidence as separate outcomes, the use of scaffolded, project-based environments allows pre-service teachers to experience authentic, practice-oriented learning that mirrors the complexity of real classroom and laboratory situations. In addition, the use of cosmetic chemistry as an applied domain highlights the value of incorporating context-rich and product-oriented tasks into teacher education. Such contexts not only enhance technical competence but also support the development of pedagogical confidence by enabling pre-service teachers to engage in meaningful, outcome-driven activities. This is particularly relevant for preparing future teachers to design and facilitate laboratory experiences that go beyond procedural instruction toward more authentic and student-centered learning.

However, the study was conducted within a single institutional setting and focused on one applied domain. As such, the transferability of the findings to other applied chemistry contexts—such as food, pharmaceutical, or agricultural chemistry—requires further investigation. Replication across multiple contexts and institutions, as well as comparative designs, would strengthen the evidence base and enable more robust conclusions regarding the generalisability of these findings.

Overall, this study provides empirical support for the integration of domain-specific, digitally supported PjBL approaches in chemistry teacher education, particularly within applied or vocational contexts. Such approaches offer a promising strategy for preparing future teachers who are both technically competent and confident in implementing innovative instructional practices (Blick *et al.*, 2024).

LIMITATIONS

Several limitations of this study should be acknowledged. First, the quasi-experimental post-test-only design, while appropriate for intact classroom settings, does not allow direct confirmation of baseline equivalence between groups. As a result, pre-



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existing differences in self-efficacy or practical skills cannot be fully ruled out. Second, both groups were taught by the same instructor, which controlled for teacher variability but may have introduced unintended enthusiasm bias toward the experimental condition. Third, as students were aware of their participation in a research study, a Hawthorne effect cannot be excluded.

Fourth, although inter-rater reliability for the observational instrument was found to be in the good range, observations were not conducted under blind conditions, as the instructional approaches were visibly distinct. This may have introduced observer bias. Fifth, the study was conducted within a single applied domain (cosmetic chemistry) at one institution, which may limit the transferability of the findings to other contexts. Future research employing pre–post designs, switching replications, or multi-site samples would strengthen the evidence base and allow for more robust conclusions. In addition, replication across other applied chemistry domains, such as food or pharmaceutical chemistry, would be valuable for examining the broader applicability of the approach.

CONCLUSION

This study demonstrates that authentic, scaffolded learning implemented through a digitally supported project-based approach significantly enhances pre-service chemistry teachers' practical skills and self-efficacy within a cosmetic chemistry context. The statistically significant differences and large effect sizes indicate that the intervention effectively supported both procedural competence and confidence in performing laboratory tasks. The findings show that practical skills development extended beyond procedural accuracy to include decision-making and product evaluation, reflecting the multidimensional nature of laboratory competence. At the same time, increased self-efficacy suggests that structured support and successful task completion provided meaningful mastery experiences that strengthened students' confidence. Crucially, the results indicate that cosmetic chemistry operates not merely as a contextual setting, but as a pedagogical domain that actively shapes learning. Its product-oriented and constraint-driven characteristics require the integration of conceptual understanding, technical execution, and evaluative judgment, thereby supporting both cognitive and affective learning outcomes.

Overall, this study highlights that the effectiveness of instructional approaches such as project-based learning depends not only on pedagogy and scaffolding, but also on alignment with domain-specific contexts. Positioning cosmetic chemistry as a pedagogical domain offers a meaningful pathway for designing chemistry learning environments that integrate skill development with learner confidence.

Author contributions

Rasamimanana Joronalona: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft.

Eli Rohaeti: Conceptualization, Methodology, Validation, Supervision, Project administration, Writing – review & editing, Funding acquisition.

Endang Widjajanti LFX: Methodology, Validation, Resources, Supervision, Writing – review & editing.

Outi Haatainen: Conceptualization, Methodology, Validation, Supervision, Writing – review & editing.

Conflicts of interest

There are no conflicts to declare

Data availability

The data supporting this study are openly available in Zenodo at <https://doi.org/10.5281/zenodo.18737240>.

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Ethical Approval Statement

This study involving human participants was conducted in accordance with relevant institutional and national guidelines and the Declaration of Helsinki. Ethical approval was granted by the Ethics Committee of the Directorate of Research and Community Service, State University of Yogyakarta (Approval No. T/6.1/UN34.9/KP.06.07 /2024).

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Data Description

The dataset supporting this study is publicly available in Zenodo at:
<https://doi.org/10.5281/zenodo.18737240>.

The dataset includes:

1. Practical skills scores based on observation rubrics
2. Self-efficacy questionnaire responses (Likert scale)

All data have been anonymized to protect participants' identities. The dataset is provided in spreadsheet format with clearly labeled variables.

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