World Journal of Chemical Education, 2026, Vol. 14, No. 3, 51-57
Available online at http://pubs.sciepub.com/wjce/14/3/3
Published by Science and Education Publishing
DOI:10.12691/wjce-14-3-3

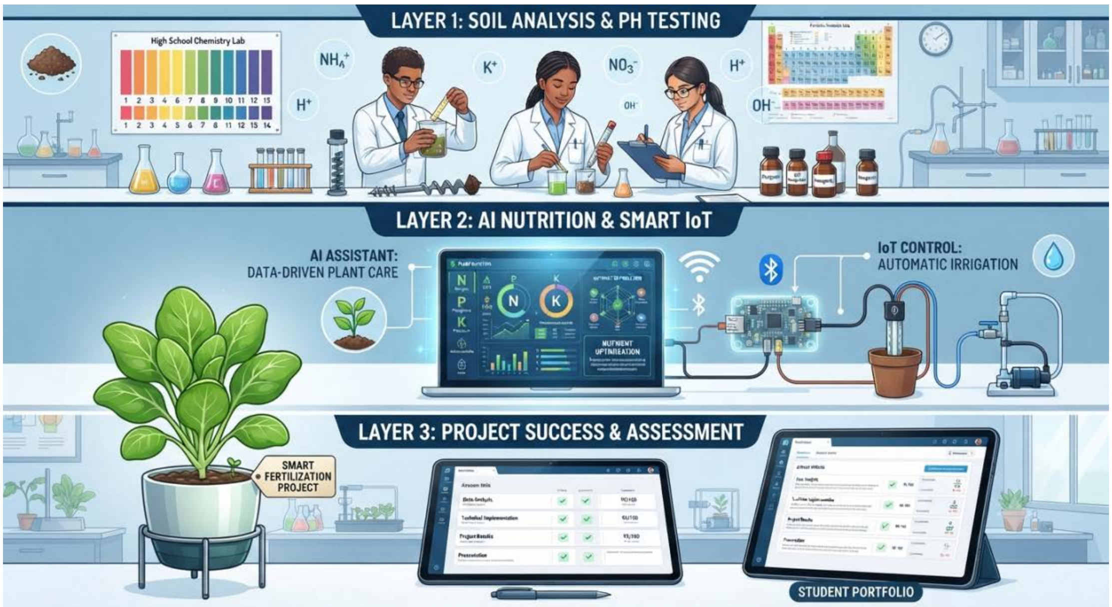
STEM Education and AI Applications in Chemistry Teaching: From Pedagogical Ecosystems to the Self-Efficacy of Secondary School Teachers

Cao Thi Van Giang[1], Cao Cu Giac[2,*]

[1]Chemistry Department, Hanoi National University of Education, Vietnam
[2]Chemistry Department, Vinh University, Vietnam
*Corresponding author: giaccc@vinhuni.edu.vn

Received August 01, 2026; Revised September 01, 2026; Accepted September 09, 2026

Abstract This study explores the integration of STEM education and artificial intelligence (AI) in chemistry teaching to foster a sustainable pedagogical ecosystem. Current secondary school practices reveal three critical operational gaps: a deficiency in interdisciplinary integration methodologies at the lower secondary level, intense high-stakes national examination pressures driving technological risk aversion at the upper secondary level, and pervasive administrative formalism in teacher professional development. To address these challenges, the research combines conceptual framework construction with an exemplary case study of a chemistry STEM project entitled "Chemical Fertilizers and Smart Agriculture". This project is structured across three progressive technical layers: direct soil pH and nutrient analysis using IoT sensors in field environments (Layer 1); the integration of large language models (such as ChatGPT) as personalized learning co-pilots alongside virtual laboratories to optimize learning trajectories (Layer 2); and the process-oriented evaluation of 21st-century competencies via a Digital Portfolio platform (Layer 3). Based on these empirical findings, the study proposes a bipolar set of breakthrough solutions: activating teachers' internal "self-efficacy" through digital self-directed learning, and reforming the "transformative mission" of teacher education institutions through the development of smart campus laboratories and professional learning networks. Finally, the study recommends institutionalizing Digital Portfolios parallel to traditional academic transcripts to alleviate high-stakes examination pressures and establish a genuine symbiotic connection between teacher education institutions and secondary schools in the AI era.



Keywords: *STEM education, artificial intelligence (AI), chemistry education, teacher self-efficacy, digital portfolio*

Cite This Article: Cao Thi Van Giang, and Cao Cu Giac, “STEM Education and AI Applications in Chemistry Teaching: From Pedagogical Ecosystems to the Self-Efficacy of Secondary School Teachers.” *World Journal of Chemical Education*, vol. 14, no. 3 (2026): 51-57. doi: 10.12691/wjce-14-3-3.

1. Introduction

1.1. Research Background

In the era of artificial intelligence (AI), big data, and global innovation, secondary education is undergoing a critical transformation [1]. Traditional, one-way knowledge transmission and rigid theoretical frameworks are no longer compatible with the cognitive patterns and knowledge acquisition methods of the younger generation. Modern secondary schools must reinvent themselves as "launchpads" that empower students to master technology and develop creative competencies. In this context, the emergence of AI is reshaping traditional classrooms by personalizing learning journeys, analyzing student absorption rates, and liberating teachers from manual administrative tasks so they can focus on fostering higher-order thinking skills in their students [2]. Consequently, establishing a comprehensive digital educational ecosystem requires an organic and robust connection between secondary schools (the implementation sites) and teacher education institutions (the core hubs guiding advanced methodologies).

Within the domain of chemistry education, bridging the gap between abstract symbolic representations and concrete real-world phenomena remains a persistent pedagogical challenge. Traditional instruction often compartmentalizes chemical concepts - such as acid-base equilibria, ion concentrations, and industrial stoichiometry- into dry, rote-learned mathematical exercises. By contextualizing chemistry teaching within agricultural soil dynamics and plant nutrition, students are engaged in active analytical chemistry practices. This approach not only provides a tangible framework for understanding pH scale and ion-exchange dynamics but also elevates agricultural chemistry from a peripheral topic to a central, inquiry-based learning platform that enhances students' conceptual integration.

1.2. Research Gaps

Despite frequent professional development programs, the reality of Chemistry and Natural Science teaching still reveals three major operational gaps. First, concerning the deficiency in interdisciplinary integration methods at the lower secondary level, teachers—traditionally trained in single disciplines such as Physics, Chemistry, or Biology—encounter substantial difficulties and disorientation when teaching integrated science courses due to a lack of a standardized methodological framework to connect fragmented knowledge threads into high-level engineering-design STEM topics [3]. Second, at the upper secondary level, intense pressure from national graduation and entrance exams makes teachers reluctant to integrate VR, simulation software, or AI into instruction. They fear falling behind schedule and compromising short-term test outcomes, which ultimately fosters a risk-averse mindset prioritizing 'teaching to the test' over genuine competency development. Finally, widespread formalism in teacher professional development characterizes administrative training sessions as piecemeal and passive, causing STEM and digital technology to serve merely as superficial displays during demonstration classes or extracurricular clubs, while teachers are left to navigate spontaneous technological information on their own during ordinary instruction [4].

1.3. Research Questions

To address the aforementioned gaps, this study focuses on answering the following four research questions:

RQ1: What specific operational gaps and psychological barriers do secondary school teachers currently face when integrating STEM and digital technology into instruction?

RQ2: How can a specific chemistry STEM topic (such as "Chemical Fertilizers and Smart Agriculture") be designed and implemented through the integration of AI tools, IoT sensors, and virtual laboratories?

RQ3: What breakthrough solutions are required to activate teachers' "self-efficacy" while simultaneously fulfilling the "transformative mission" of teacher education institutions to establish a sustainable ecosystem?

RQ4: How should assessment and evaluation mechanisms (particularly Digital Portfolios) be reformed to harmonize with high-stakes national examination pressures?

2. Research Methodology

This study employs a combination of conceptual framework construction and exemplary case study methodologies:

(i) Conceptual Framework Construction Method: This involves analyzing and synthesizing specialized literature regarding the symbiotic relationship between secondary schools and teacher education institutions, as well as examining the psychological and technical barriers faced by secondary school teachers in the context of educational innovation.

(ii) Exemplary Case Study Method: This entails designing an integrated STEM project utilizing AI and digital technologies, directly applied to the topic of "Chemical Fertilizers and Smart Agriculture" within the secondary chemistry curriculum. The technical design process of the project is structured into progressive layers, ranging from field data collection and biological fertilizer preparation to the application of AI tools and virtual laboratories for optimizing the learning trajectory [5].

(iii) Modeling and Solution Proposition Method: This synthesizes bipolar sets of solutions aimed at activating teachers' internal drive ("self-efficacy") and restructuring the training system of teacher education institutions ("transformative mission"). Furthermore, it proposes a framework for institutionalizing "Digital Portfolios" accompanied by multidimensional evaluation rubrics.

3. Results and Discussion

3.1. Analysis of "Operational Gaps" and Teachers' Psychological Barriers

The analysis of current practices reveals that the primary barriers do not stem from a lack of technology, but rather from integrated methodologies and high-stakes testing pressures [6]. Lower secondary school teachers experience professional crises when tasked with teaching integrated subjects due to the lack of a reference framework to connect Physics, Chemistry, and Biology knowledge into a coherent, comprehensive STEM topic [7]. At the upper secondary level, the pressure of national examinations dictates obsolete teaching methods. The perceived fear of technology is, in essence, a fear of losing valuable class time dedicated to test preparation [8]. Furthermore, administrative formalism in professional development fosters a superficial, compliance-driven mindset, marginalizing STEM and digital technology to the periphery of classroom instruction where they are merely used as performative displays during inspections or demonstration classes.

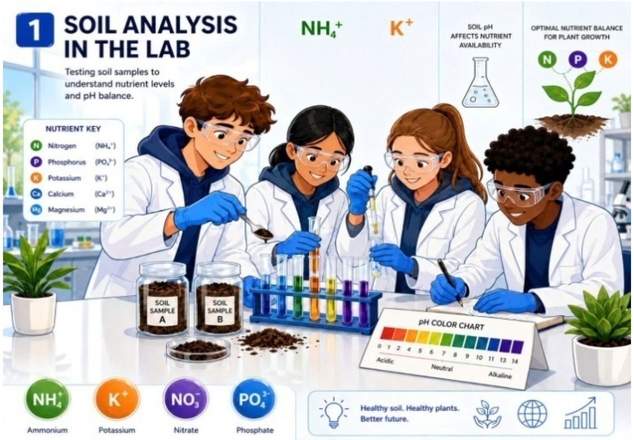
3.2. Exemplary Case Study: Designing the STEM Topic "Chemical Fertilizers and Smart Agriculture"

To demonstrate the feasibility of integrating STEM and technology, the project entitled "Smart Soil Nutrient Management Model and Safe Production/Application of Bio-Chemical Fertilizers" is structured and clarified through three technical layers closely linked to local realities and digital technology as follows:

Layer 1: Soil Analysis and pH Testing

Layer 1 of the project marks a significant shift from traditional teaching methods to practical, hands-on application. Instead of rote memorization of dry inorganic industrial production equations, students are introduced to local field environments to directly measure soil pH using IoT sensors. Through activities combining chemistry laboratories and field environments, students directly analyze core chemical indicators of the soil, such as pH and nutrient ions (NH_4^+, K^+, NO_3^- , etc.), thereby grasping the intrinsic nature of the cultivation environment intuitively rather than relying solely on theoretical study [9] (Figure 1).

It is critical to distinguish this pedagogical application of 'soil testing' from purely technical agricultural diagnostics. In this research design, soil analysis serves as an authentic analytical chemistry laboratory. Instead of passively memorizing theoretical equations of industrial fertilizer synthesis (such as the Haber-Bosch process or superphosphate production), learners confront real-world chemical systems. They utilize IoT-enabled pH sensors to investigate soil acidity, which directly connects to the thermodynamic behavior of chemical equilibria and the solubility of essential plant nutrients. Furthermore, detecting and quantifying major nutrient ions (NH_4^+, K^+, NO_3^-) introduces students to quantitative ion analysis and concentration gradients. This pedagogical shift transforms abstract chemical symbols into measurable, real-world variables, thereby cultivating students' analytical minds within a concrete chemistry context.



(Source: Designed by the authors; captured directly during the actual experimental and field chemistry activities of the school deployment, with student representations simulated/rendered using generative AI to strictly protect personal privacy and ensure ethical research compliance)

Figure 1. Soil pH and nutrient analysis using IoT sensors in field and laboratory environments

Layer 2: AI Integration and Smart IoT Nutrition

At the second layer, the project focuses deeply on applying artificial intelligence and digital technology to crop management processes. Students utilize large language models, typically ChatGPT, as an effective learning assistant to retrieve data on crop nutritional requirements across different climatic regions, while receiving support in drafting reports and critiquing designs. Additionally, IoT control systems are established to automate irrigation processes based on collected data [10]. Notably, for complex or hazardous chemical experiments, students practice beforehand in virtual laboratories to visualize the microstructures of chemical reactions prior to conducting them in reality (Figure 2).

(Source: Designed by the authors; original user interface designs and screenshots captured from the authors' educational technology platform)

Figure 2. Integration of generative AI (ChatGPT) and virtual chemistry laboratories for smart nutrition modeling

Layer 2 leverages generative AI (ChatGPT) and virtual chemistry laboratories to address a classic threshold concept in chemical education: the connection between the macroscopic, submicroscopic (molecular), and symbolic levels of representation (Johnstone's Triangle). While IoT sensors in Layer 1 capture macroscopic data (such as soil pH and ion concentrations), these physical observations are inherently limited to the visible spectrum. The integration of interactive virtual chemistry simulations allows students to zoom into the submicroscopic level, visualizing the molecular dynamic interactions of ion dissociation, hydration spheres, and nutrient uptake at the root membrane interface. Concurrently, ChatGPT serves as an adaptive pedagogical scaffold, translating complex thermodynamic data and chemical reaction mechanisms into customized, cognitive-level-appropriate explanations, thereby bridging the representation gaps that frequently hinder conceptual understanding in chemistry learning.

Layer 3: Project Success and Assessment

The final layer serves as a summary and comprehensive evaluation phase of student learning processes through the Digital Portfolio platform [11]. This portfolio acts as a core repository documenting the entire progression of students' STEM projects, including technical designs, videos, presentations, and research reports. Student evaluation moves away from rote memorization, employing a multidimensional assessment rubric framework to accurately measure 21st-century competencies such as problem-solving, design thinking, creativity, and collaborative teamwork (Figure 3).

(Source: Designed and conceptualized by the authors)

Figure 3. Multidimensional assessment of 21st-century student competencies via the Digital Portfolio platform

Thus, the project establishes a major breakthrough by completely shifting away from traditional instructional methods; instead of forcing students to memorize dry inorganic industrial production equations, the model immerses learners directly into local practices through soil pH measurement using IoT sensors in Layer 1 [12]. Building upon this practical foundation, Layer 2 powerfully harnesses artificial intelligence and digital technology as students utilize large language models (such as ChatGPT) as learning assistants to retrieve nutritional data, support report writing and design critique, and experience virtual laboratories to visualize the microstructural dynamics of reactions prior to physical execution [13]. Finally, Layer 3 concludes the learning trajectory through the Digital Portfolio platform and a multidimensional assessment rubric framework, comprehensively measuring 21st-century competencies and affirming the superiority of a STEM educational ecosystem deeply intertwined with real-world practices (see Appendix).

3.3. Breakthrough Solutions: From "Self-Efficacy" to "Transformative Mission"

To scale up practical STEM models, simultaneous interventions must target two primary stakeholders:

3.3.1. Activating the "Self-Efficacy" of Secondary School Teachers

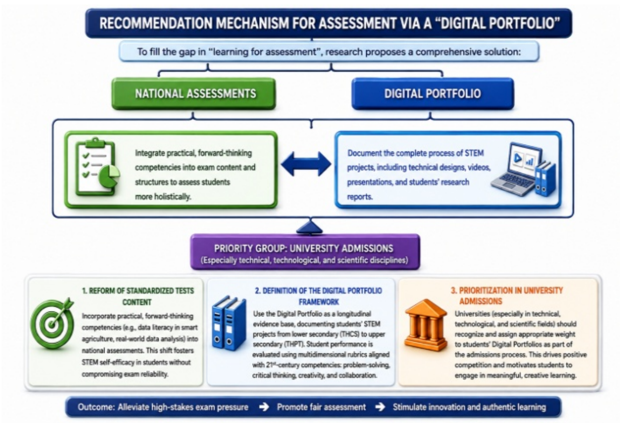
Professional development for educators is only effective when they proactively cultivate four core groups of self-directed competencies. First, teachers must develop integrated design and critical thinking skills, enabling them to autonomously restructure curricula to fit local realities and selectively curate digital learning resources rather than depending solely on textbooks [14]. Second, they need to cultivate digital self-directed learning capabilities by establishing a habit of exploring global open educational resource repositories and mastering artificial intelligence in designing STEM scenarios, rather than passively waiting for administrative training sessions [15]. Third, educators must master classroom project management and process-based assessment skills to proficiently manage student group activities in open learning spaces and evaluate performance based on authentic product verification rubrics [16]. Finally, engaging in action research allows teachers to transform their classrooms into experimental spaces for self-reflection, methodological adjustment, and the accumulation of sustainable professional assets [17].

3.3.2. Innovating the "Transformative Mission" of Teacher Education Institutions

Teacher education institutions must decisively abandon purely academic and theoretical training models by implementing three core pillars of action. First, they must reform practical professional development curricula by designing specific modules focused on applying artificial intelligence to create agricultural chemistry STEM learning materials and implementing integrated teaching methods [18]. Second, these institutions need to build digital practical ecosystems by investing in smart teaching laboratories integrated with IoT and virtual reality directly on campus, allowing both pre-service students and in-service secondary teachers to gain direct, hands-on experience [19]. Third, establishing a network of experts closely embedded in grassroots practices is essential; teacher educators should directly participate in professional learning communities with secondary school subject departments to troubleshoot technical bottlenecks. Furthermore, graduate training programs must immerse students in real-world educational technology projects, such as developing simulation software or AI-driven assessment question generation systems, while simultaneously reforming faculty dual-competency evaluation policies by reducing teaching workloads for faculty members leading applied international publication projects.

3.4. Recommended Assessment Mechanisms via Digital Portfolios

To dismantle the bottleneck of "teaching to the test," the study proposes a comprehensive bipolar solution. First, standardized tests must be reformed by integrating high-order thinking practical scenarios - such as calculating nutrient content within smart agricultural models or analyzing real-world data - into national examinations, thereby back-mapping and empowering teachers to confidently implement STEM instruction without fearing misalignment with test outcomes. Second, Digital Portfolios should be institutionalized as a core evidentiary artifact running parallel to official academic transcripts, systematically archiving the entire trajectory of students' STEM projects from lower to upper secondary education and evaluating performance through multidimensional rubrics that accurately measure 21st-century competencies including problem-solving, design thinking, creativity, and collaboration [20]. Third, higher education institutions - particularly in technical, technological, and pedagogical fields - must recognize and assign flexible admission weightings to students' Digital Portfolios, providing the ultimate incentive to alleviate examination pressure and spark genuine innovative learning [21] (Figure 4).



(Source: Designed and conceptualized by the authors)

Figure 4. Mechanism for assessing students' chemistry learning competencies via the "Digital Portfolio"

4. Conclusion

The development of STEM educational competencies and the integration of digital technology in the artificial intelligence (AI) era do not represent a transient administrative movement, but rather a profound, systemic transformation in chemistry teaching culture. When chemistry topics - classically perceived as highly abstract and symbolic - are grounded in real-world contexts such as smart agricultural soil dynamics and sustainable fertilizer ecosystems, chemistry education is liberated from rote memorization. Exploring these practical phenomena through the lens of digital tools enables students to construct deep, intuitive cognitive frameworks, thereby achieving fundamental leaps in learning quality.

Crucially, this pedagogical transition demands a radical paradigm shift in chemistry teacher education. Teacher education institutions must proactively abandon obsolete, purely theoretical training models and embrace a transformative mission. This involves reforming university curricula to embed specialized modules on AI-assisted chemistry material design and integrated STEM methodologies. Furthermore, establishing digital practice ecosystems on university campuses - such as smart laboratories integrated with IoT sensors and virtual reality simulations - is imperative to provide pre-service chemistry teachers with direct, hands-on technological experience. By building active expert networks that directly collaborate with and support secondary school chemistry departments, teacher education institutions can bridge the operational gaps in grassroots practices and cultivate a new generation of highly adaptive educators.

Ultimately, the symbiotic connection between teacher education institutions and secondary schools serves as the cornerstone for a sustainable digital educational ecosystem. The harmonious combination of secondary school teachers' activated internal self-efficacy, the proactive transformative mission of teacher education institutions, and the institutionalization of Digital Portfolios as breakthrough assessment mechanisms provides a robust launchpad. This tripartite synergy not only alleviates high-stakes examination pressures but also empowers the younger generation of both chemistry teachers and students to readily shoulder the mission of national development in the digital age.

Supporting Information

Appendix: MULTIDIMENSIONAL ASSESSMENT RUBRICS FOR DIGITAL PORTFOLIOS

(Applied to the STEM Chemistry Topic: "Chemical Fertilizers and Smart Agriculture")

(DOCX)

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

We would like to thank the School of Education - Vinh University for supporting us in this research.

References

[1] Khan, M., Ahmed, A., & Sharif, M. M. (2026). AI infused business model innovation for competitive advantage in the era of big data and digital transformation. Open Access Journal of Data Science and Artificial Intelligence, 4(1), 1-21.

[2] Bhutoria, A. (2022). Personalized education and artificial intelligence in the United States, China, and India: A systematic review using a human-in-The-Loop model. Computers and Education: Artificial Intelligence, 3, 100068.

[3] Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004).

Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. Science Education, 88(4), 610-645.

[4] Costa, M. C., Domingos, A. M., Teodoro, V. D., & Vinhas, É. M. (2022). Teacher professional development in STEM education: An integrated approach with real-world scenarios in Portugal. Mathematics, 10(21), 3944.

[5] Thi Van Giang, C., Thi Thu Hiep, L., & Cu Giac, C. (2026). A five-step framework for designing augmented reality laboratories in pre-service chemistry teacher education: A case study on essential oil extraction. World Journal of Chemical Education, 14(2), 26-35.

[6] Stillman, J. (2011). Teacher learning in an era of high-stakes accountability: Productive tension and critical professional practice. Teachers College Record: The Voice of Scholarship in Education, 113(1), 133-180.

[7] Anderson, J., & Tully, D. (2020). Designing and evaluating an integrated STEM professional development program for secondary and primary school teachers in Australia. Advances in STEM Education, 403-425.

[8] Mete, P. (2021). Structural relationships between coping strategies, self-efficacy, and fear of losing one's self-esteem in science class. International Journal of Technology in Education and Science, 5(3), 375-393.

[9] Kurhak, V. G., & Karbivska, U. (2025). Productivity of sowed cereal grass depends on the doses and ratio of nitrogen, phosphorus and potassium fertilizers. Agriculture and plant sciences: theory and practice, (2), 72-81.

[10] García Ramos, J., De Souza Júnior, R. S., & Borges, E. M. (2025). How digital images are transforming chemical education: A review of laboratory-based applications. ACS Omega, 10(30), 32651-32672.

[11] Bennett, D., Rowley, J., Dunbar-Hall, P., Hitchcock, M., & Blom, D. (2014). Electronic portfolios and learner identity: An ePortfolio case study in music and writing. Journal of Further and Higher Education, 40(1), 107-124.

[12] Giac, C. C., Hang, N. T., & Giang, C. T. (2025). STEM education in natural science teaching to secondary school students: Case study of making a pH measuring pen in soil application of IoT technology. Journal of Chemical Education, 102(4), 1518-1528.

[13] Kamduri, V. R., Gupta, P., & El Kari, C. (2026). AgriGen: A prompt-tuned, multilingual LLM-based Q&A system for smarter agriculture. Lecture Notes in Computer Science, 190-200.

[14] Branchetti, L., Nipyrakis, A., Satanassi, S., Bitsaki, C., Pipitone, C., Stavrou, D., & Levrini, O. (2026). Theoretical underpinnings and empirical findings for designing interdisciplinary boundary zones for teacher education. Science & Education.

[15] Giac, C. C., Giang, C. T., Hoang, L. H., & Ngan, T. T. (2025). A study on teachers' acceptance of digital technology in Vietnamese secondary education: An assessment using the technology acceptance model. International Journal of Learning, Teaching and Educational Research, 24(2), 38-62.

[16] Cao, G. C., & Le, H. T. (2024). Organizing activities for chemistry pedagogy students to research and practice extracting cajeput essential oils from Melaleuca leaves using the CDIO approach. Vietnam Journal of Education, 121-137.

[17] Laurillard, D. (2008). The teacher as action researcher: Using technology to capture pedagogic form. Studies in Higher Education, 33(2), 139-154.

[18] Magaji, A., & Ade-Ojo, G. (2023). Trainee teachers' classroom assessment practices: Towards evaluating trainee teachers' learning experience in a teacher education programme.

[19] Ilmudeen, A. (2022). Artificial intelligence, big data analytics and big data processing for IoT-based sensing data. Transforming Management with AI, Big-Data, and IoT, 247-259.

[20] Ahn, H., & Kim, H. (2025). Impact of teaching practicum experiences through teaching portfolios on the agency of pre-service science teachers. Brain, Digital, & Learning, 15(2), 191-203.

[21] Lam, R., & Moorhouse, B. L. (2022). Digital portfolios for assessment. Using Digital Portfolios to Develop Students' Writing, 37-53.

APPENDIX: MULTIDIMENSIONAL ASSESSMENT RUBRICS FOR DIGITAL PORTFOLIOS

(Applied to the STEM Chemistry Topic: "Chemical Fertilizers and Smart Agriculture")

The Digital Portfolio is a multidimensional assessment mechanism designed to document and evaluate student learning progression, engineering design practices, and technological integration throughout the STEM project1. Grounded in the standards of 21st-century education, this rubric prioritizes process-oriented performance, critical thinking, and collaborative problem-solving rather than rote memorization.

1. MULTIDIMENSIONAL ASSESSMENT RUBRIC TABLE

Criterion & Weight	Level 1: Needs Improvement *(1 point)*	Level 2: Pass *(2 points)*	Level 3: Proficient *(3 points)*	Level 4: Exemplary *(4 points)*
Engineering Design & IoT Model *(Weight: 25%)*	Technical design is superficial and lacks interdisciplinary integration. The IoT measurement device (pH/moisture) is highly unstable or produces inaccurate soil metrics, failing to provide useful field data.	The technical design has a basic structure but lacks optimization. The IoT device functions under guidance but exhibits technical glitches and unstable wireless data transmission.	The technical design is clear and demonstrates sound interdisciplinary integration (Chemistry, Biology, Technology). The IoT model operates stably, collecting accurate soil pH/moisture data from the field.	The technical design is breakthrough and professional. The compact IoT model features automated real-time data transmission and optimized watering/fertilizer control based on real-time soil analysis.
Project Journal & Research Report *(Weight: 20%)*	Journal entries are sporadic, inconsistent, and highly superficial. The final research report lacks empirical data or presents ambiguous results. Inability to utilize virtual laboratories.	Journal entries are documented but lack in-depth analysis and self-reflection. The research report contains field data but only basic descriptive	The journal clearly reflects the iterative learning process and active self-reflection. The research report sharply analyzes local soil dynamics and proposes	The journal serves as an outstanding, professional action-research document. The research report integrates advanced, peer-reviewed level literature on green agriculture and soil

Criterion & Weight	Level 1: Needs Improvement *(1 point)*	Level 2: Pass *(2 points)*	Level 3: Proficient *(3 points)*	Level 4: Exemplary *(4 points)*
		analysis. Virtual lab usage is perfunctory.	appropriate organic/bio-fertilizer formulas. Good application of virtual labs.	ion exchange. Exceptional, creative use of virtual labs.
AI Integration & Critical Thinking *(Weight: 20%)*	No AI utilization, or passive/unverified reliance on AI tools (e.g., direct copying from ChatGPT/LLMs without verification). Absence of critical thinking regarding digital resources.	Uses AI to retrieve basic information regarding soil chemistry and fertilizers, but lacks advanced prompting skills. Information cross-checking is superficial.	Demonstrates creative AI integration (multi-step prompting with clear instructional intent) to retrieve nutritional formulas. Actively cross-checks and critiques AI outputs against empirical field experiments.	Commands AI as an effective, highly personalized learning co-pilot. Designs optimized prompt templates; masterfully utilizes AI for project planning, structural design critique, and independent problem-solving.
Oral Presentation & Digital Deliverables *(Weight: 15%)*	Video quality is substandard, featuring blurry audio or visual formatting. The presentation is monotonous, simply reading from slides. Digital deliverables are incomplete or buggy.	Video and audio are clear, but the design lacks creativity and has suboptimal duration. The oral presentation covers all basic project aspects but lacks engaging delivery or rhetorical impact.	The video is professional, featuring crisp audio-visual aesthetics and a logical structural layout. Students confidently present the project's progress with coherent arguments, highlighting experimental results.	The video is highly artistic, persuasive, and inspiring. Seamlessly incorporates advanced infographics and real-time field data. Delivery is exceptionally compelling with outstanding defense during Q&A.
Team Collaboration & Problem Solving *(Weight: 20%)*	Disjointed division of labor with minimal coordination. When encountering field bottlenecks (e.g., sensor errors, highly acidic soil), the team fails to troubleshoot and relies entirely on the teacher.	Group work is evident, but the workload distribution is unequal. Solves minor problems using simple, low-efficiency trial-and-error methods without systemic reasoning.	Fair division of tasks and smooth, harmonious collaboration. Proactively troubleshoots technical sensor errors and proposes biochemically effective solutions to neutralize soil acidity.	Outstanding team operations with shared, peer-to-peer leadership. Solves problems with highly innovative, sustainable, and community-oriented solutions (e.g., formulating cost-effective, localized organic fertilizers).

2. SCORING AND GRADING GUIDELINES

2.1. Portfolio Composite Score (10-Point Scale Conversion)

To convert the raw rubric points into a standardized 10-point scale academic mark, use the following weighted formula:

Composite Score = (C_1 × 0.25 + C_2 × 0.20 + C_3 ×0.20 + C_4 × 0.15 + C_5 × 0.20) × 2.5

Where C_1 to C_5 represent the scores (1 to 4) achieved in each of the five respective criteria.

2.2. Academic Performance Classification

Exemplary (9.0 – 10.0): Masterful integration of interdisciplinary STEM concepts (IoT, AI, and chemistry simulations) to solve real-world problems. The deliverables are professional-grade, innovative, and show complete conceptual mastery.

Proficient (8.0 – 8.9): Solid application of scientific knowledge and digital tools to address local agricultural issues. Displays strong self-reflection, high-quality digital media, and coordinated teamwork.

Developing (6.5 – 7.9): Meets the fundamental standards of the STEM project. Demonstrates average technological integration, but solutions lack optimal engineering design or deep critical analysis.

Basic (5.0 – 6.4): Minimum requirements met, but portfolio evidence is sparse. Technical sensor models or chemical explanations are weak, fragmented, or incomplete.

Unsatisfactory (Below 5.0): Key portfolio deliverables are missing (e.g., no functional IoT prototype, absent journal entries, or failed digital products). Reflects insufficient engagement or lack of team collaboration.