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Integrating Chemistry, Information Technology, and Entrepreneurship Through Project-Based Learning: A Framework for Enhancing Digital and Entrepreneurial Competencies in Undergraduate STEM Education

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ABSTRACT

This study investigates the effectiveness of integrating chemistry, information technology, and entrepreneurship through a structured project-based learning (PBL) framework in an undergraduate chemistry course at Universiti Pendidikan Sultan Idris, Malaysia. The program, implemented over 14 weeks with 127 students, aimed to bridge theoretical chemical knowledge with practical entrepreneurial and digital skills. Students worked in teams through five sequential phases: orientation, research, product development, marketing, and public showcase, culminating in the creation and commercialization of healthcare or agricultural products. Data from reflections and surveys revealed that the PBL approach enhanced students' confidence, communication abilities, digital literacy, and entrepreneurial mindset. Participants valued the opportunity to apply theoretical concepts to real-world contexts while developing transferable skills for innovation-driven careers. The findings highlight PBL as a replicable model for fostering active learning, curriculum relevance, and student agency in STEM education, with potential to prepare graduates for the demands of the 21st-century workforce.

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1. INTRODUCTION

In the current era of rapid technological advancement, the integration of chemistry and information technology offers significant opportunities for innovation and entrepreneurship. Higher education must respond to these changes by preparing students not only with strong disciplinary knowledge but also with the ability to apply this knowledge in interdisciplinary and real-world contexts. In Malaysia, the demand for graduates with digital literacy, entrepreneurial capability, and problem-solving skills continues to grow, particularly in science, technology, engineering, and mathematics (STEM) fields. Many reports regarding STEM have been well-developed (Camilon *et al*., 2025; Fitriani *et al*., 2024; Rahmi *et al*., 2025; Solihah *et al*., 2024).

The Information and Communication Technology in Chemistry course addresses this need through a project-based learning (PBL) approach. PBL, grounded in constructivist principles, emphasizes learning by doing, collaborative problem-solving, and reflective practice. It has been shown to improve academic achievement, foster transferable skills, and enhance student engagement compared to traditional lecture-based instruction (Arifiani *et al*., 2025). Within this framework, students work in teams to design, develop, and market innovative products that apply chemical concepts to real-world challenges in healthcare and agriculture, while integrating information technology for design, analysis, and promotion.

This paper presents the SKI.ENT project, a structured PBL model that bridges theoretical chemistry, digital technology, and entrepreneurial practice. The study aims to evaluate its effectiveness in fostering practical application of chemistry knowledge, enhancing digital and entrepreneurial competencies, and promoting student agency. The novelty of this work lies in its interdisciplinary integration within a single course framework, demonstrating how STEM curricula can be adapted to cultivate innovation-driven graduates ready for the challenges of the 21st-century workforce.

2. METHODS

This study employed a project-based learning (PBL) approach grounded in constructivist theory, particularly the experiential learning principles articulated by John Dewey, which emphasize active engagement, hands-on experiences, and reflective practice. PBL has been widely recognized for its capacity to enhance both disciplinary knowledge and transferable skills, particularly in STEM education. It fosters critical thinking, collaboration, self-directed learning, and the integration of theory with practice.

The SKI.ENT framework was implemented in the Information and Communication Technology in Chemistry course at Universiti Pendidikan Sultan Idris (UPSI) over a 14-week semester with 127 undergraduate chemistry students. The instructional design consisted of five sequential phases: (i) orientation and team formation, (ii) research and problem identification, (iii) product development, (iv) marketing and communication, and (v) public showcase. Students, working in teams of 4–5, developed innovative products in healthcare or agriculture by applying chemical principles, incorporating information technology, and planning commercialization strategies.

Learning activities included market analysis, literature review, laboratory experimentation, prototyping, technical workshops, and the creation of digital marketing materials. Students maintained e-portfolios documenting weekly progress, integrating digital tools such as Google Sites for design thinking and presentation purposes. Assessment was continuous and multifaceted, evaluating research quality, documentation, teamwork, product innovation, marketing effectiveness, and business viability.

The course design was supported by faculty advisors and industry mentors, access to dedicated laboratory facilities, and structured reflection activities. This combination of academic guidance, industry insight, and technological integration provided a comprehensive learning environment aimed at bridging theoretical chemistry knowledge with digital and entrepreneurial skills relevant to the 21st-century workforce.

3. RESULTS AND DISCUSSION

Project-based learning represents an educational methodology grounded in the constructivist principles articulated by John Dewey (Sah, 2024). This pedagogical framework operates on the fundamental premise that effective learning occurs organically through active engagement, hands-on experiences, and reflective examination of concepts among students. The implementation of project-based learning has demonstrated significant value across diverse educational sectors. Within vocational training environments, this methodology has consistently shown its capacity to cultivate practical competencies and research capabilities while simultaneously fostering positive values and professional attitudes (Isa & Azid, 2021). Furthermore, project-based learning facilitates comprehensive knowledge integration, enables cross-disciplinary collaboration, and enhances student engagement and motivation. Many findings proved that project-based learning cultivates critical competencies, analytical thinking capabilities, and essential personal characteristics. The methodology's comprehensive nature addresses both academic achievement and practical skill development, making it a holistic educational strategy that prepares students for multifaceted professional challenges (Almulla, 2020).

The convergence of technological advancement with project-based learning methodologies represents a pivotal educational innovation in contemporary pedagogy. The incorporation of technology's inherent collaborative and interactive capabilities through information and communication technology learning environments directly aligns with the digital learning preferences characteristic of twenty-first-century students (Belda-Medina, 2021). This student-centered approach demonstrates its effectiveness by fostering independent inquiry capabilities and research competencies among learners. The methodology enables students to develop comprehensive deliverables encompassing products, presentations, and performances with technology functioning as both a supporting mechanism and an enhancement tool for achieving targeted learning outcomes (Chung *et al*., 2020). Consequently, this integrated approach strengthens students' technological literacy and professional attitudes while simultaneously developing complementary competencies in analytical thinking, professional communication, and innovative problem-solving that underpin effective knowledge construction.

PBL serves as the pedagogical foundation of SKI.ENT that offers a student-centered instructional approach that has proven particularly effective in STEM education (Crespí *et al*., 2022). Within the SKI.ENT framework, PBL creates authentic learning experiences where chemistry students actively engage with real-world challenges, aligning with Dewey's pragmatic educational philosophy of learning by doing (Efstratia, 2014). This methodology supports the development of 21st-century skills, including critical thinking, collaboration, and self-directed learning, which are essential for entrepreneurial success in the chemistry- technology nexus. SKI.ENT's implementation of PBL involves students working collaboratively over 14 weeks to research, design, develop, and market innovative healthcare or agricultural products, mirroring professional practices in chemical entrepreneurship. This approach is consistent with previous research (Zhang, 2023) demonstrating that PBL significantly improved students' learning outcomes and positively contributed to academic achievement, affective attitudes, and thinking skills, especially academic achievement, compared to traditional lecture-based instruction (Zhang & Ma, 2023). By bridging chemistry, information technology, and entrepreneurship through structured PBL experiences, SKI.ENT creates a learning environment that not only enhances disciplinary knowledge but also cultivates the innovative mindset and practical skills graduates need to create their career opportunities in an increasingly competitive and dynamic global economy (Patel *et al*., 2024).

3.1. SKI.ENT Project-Based Learning Activity Framework

The SKI.ENT project-based learning (PBL) framework was implemented over a 14-week semester through five sequential phases designed to integrate chemistry knowledge with entrepreneurial skills. The program commenced with orientation and team formation (Weeks 1–2), where students were introduced to chemistry-based entrepreneurship through targeted presentations. They formed diverse teams of 4–5 members and participated in ideation workshops focusing on healthcare and agriculture, while exploring available digital tools and resources (See **Table 1**).

In the subsequent problem identification and research phase (Weeks 3–4), teams conducted market analyses, reviewed relevant scientific literature, and developed initial project proposals linking chemical principles to real-world applications. The design and development phase (Weeks 5–9) involved iterative prototyping during laboratory sessions, detailed documentation of experimental work, participation in technical skill workshops, and a mid-project review to receive structured feedback. During Weeks 10–12, attention shifted to marketing and communication strategies. Students performed competitive analyses, created digital marketing content, including websites and promotional materials, and refined their communication skills through pitch rehearsals and e-portfolio workshops. The final phase (Weeks 13–14) focused on implementation and public presentation. Teams conducted product testing and quality assurance, developed simplified business plans, and showcased their innovations at the SKI.ENT showcase event.

Assessment was evenly distributed between ongoing evaluations of research output, documentation, team collaboration, and final deliverables, including product quality, marketing effectiveness, and business viability. The program was supported by faculty advisors, industry mentors, dedicated lab access, and structured reflection activities, providing students with a comprehensive platform to apply chemistry in innovative and entrepreneurial contexts.

Table 1. Summarize the six stages of the SKI.ENT project-based learning.

Stage	Phase	Activities
1	Discovery and Ideation Phase	Students identified chemistry-related challenges and opportunities that could be addressed through technology. Working in collaborative teams, they conducted preliminary research and brainstorming sessions to generate viable product concepts.
2	Research and Validation	Teams conducted in-depth research to validate their ideas, examining scientific literature, market needs, and existing solutions. This phase also incorporated laboratory experimentation, where appropriate, to test and confirm chemical principles.
3	Product Development	Students developed prototypes or minimum viable products (MVPs) that demonstrated their understanding of both chemical concepts and applications of information technology. These included software applications, analytical tools, educational platforms, and physical products integrated with digital components

Table 1 (Continue). Summarize the six stages of the SKI.ENT project-based learning.

Stage	Phase	Activities
4	Business Model Creation	Each team created a comprehensive business model for their product, encompassing target market analysis, value propositions, revenue streams, and cost structures. This phase emphasized the connection between scientific innovation and commercial viability.
5	Digital Marketing Campaign	Students designed and implemented digital marketing strategies using various platforms and technologies to promote their products. They created digital content, leveraged social media, and developed online promotional materials and presentations.
6	Pitch and Showcase	The program culminated in a formal presentation where teams pitched their products to faculty members, peers, and industry representatives. This final event simulated a real-world investor pitching environment, offering valuable experience in public communications and professional engagement.

3.2. Students' perception of SKI.ENT Project-Based Learning

Students were asked to do a reflection after finishing the project. Based on students' feedback, three keywords are chosen to represent the most significant aspects of this project, namely learning new knowledge, creating and selling products. The gathered feedback will be used for improvement in the next project. In general, students expressed positive experiences from completing the project. Many students highlighted that this project was fun and an enriching experience (eg, S85: I enjoyed the project; S106: It was very fun and I learned a lot of new things when I handled the project; S62:It's a good experience). Nearly all students agreed that the SKI.ENT opened the opportunity for them to gain practical knowledge and developed soft-skills such as planning, communication, and teamwork, which allowed them to contribute ideas and work diligently towards a shared goal (eg. S70: The project is well-organized and creative. It allows me to propose the planning for our products and work hard for it. It is a new experience for me, and I am delighted to participate in this project. The assessment conducted throughout this project was effective because students felt that projects like this should be continued (eg, S102: This project should be done in the next session student too). This PBL approach not only fosters active participation but also creates a motivating and rewarding learning environment that students find both memorable and educational.

Based on the survey, 109 students (97.3%) agreed that 10 weeks was sufficient time to complete the project. For instance, one student (S93) mentioned, “I think 10 weeks given are enough to complete this project perfectly,” reflecting a common sentiment that the timeline was well-suited to the scope of the work involved. These responses suggest that most students were able to plan and manage their tasks effectively within the given timeframe, balancing both the creative and technical aspects of the project. Meanwhile, 3 students (2.7%) need extra time to complete the project (eg, S98: I hope the time given should be extended since this project needs to have a lot of trial and error). These students likely encountered complexities in developing products that may need several tests and analyses. Hence, it does not fit comfortably within the 10 weeks. This feedback suggests that allowing optional flexibility or extended support in specific phases could enhance the experience for those who need more time to improve their outcomes.

One of the key aspects students enjoyed most about the project was the opportunity to acquire new knowledge and practical skills that extended beyond their usual academic experience. For instance, students report their weekly progress in an e-portfolio using the Google site, which introduced them to design thinking and digital presentation skills, as stated by S7 and S56. Another student (S17) shared that creating promotional videos allowed them to develop communication and creativity skills from a new perspective, which they had never done before. This illustrates that students valued the learning process and experience of discovering new tools and digital competencies to complete this project. PBL substantially strengthens multiple dimensions of digital literacy, encompassing technical proficiency, information evaluation and retrieval abilities, collaborative online competencies, digital content creation capabilities, and analytical thinking skills in digital contexts (Hawa *et al.*, 2024).

"S7: I learn something new about how to make an e-portfolio look interesting

S56: Editing the e-portfolio. Because that is my first time knowing about Google Sites, and I had so much fun editing it.

S17: I enjoyed the most when I was responsible for making promotion videos since I had never had experience with that task."

From the survey, students found enjoyment in creating their product, which provided meaningful learning experiences. For example, S18 and S43 mentioned that making the product was fun and giving a chance to learn new things, suggesting that the task given enhanced their knowledge and skills. S41 highlighted their excitement in creating the henna product, showing their sense of ownership and personal involvement. Furthermore, students enjoy selling their products because they build their confidence in persuading others to buy their products. S92 highlights the impact of presentation and promotion activities in selling their products, which are able to build confidence in public speaking and persuasive communication. It indicates that students foster active learning and learning the product development process that is related to their real-life experiences.

SKI.ENT project potentially to fill up the gap between theoretical and practical knowledge as well as soft skills. PBL can promote student involvement, practical knowledge, and self-directed learning compared to traditional learning (Mutanga, 2024). This emphasis on PBL enhances knowledge retention (Zhang, 2023) and provides students with skills that are able to be used in work environment (Astarina, 2020).

4. CONCLUSION

The SKI.ENT project demonstrated the transformative potential of integrating chemistry, information technology, and entrepreneurship through project-based learning in higher education. By engaging students in authentic, interdisciplinary problem-solving, the program strengthened core chemical knowledge while cultivating creativity, collaboration, digital competence, and entrepreneurial thinking. Student feedback confirmed high levels of engagement, satisfaction, and skill acquisition, particularly in applying theory to practice and developing market-ready innovations. The structured PBL framework provided a balance of guidance and autonomy, enabling effective time management and self-directed learning. To further enhance outcomes, future iterations could incorporate flexible timelines and expanded mentorship for complex product development. Overall, SKI.ENT offers a scalable and adaptable model for preparing STEM graduates with the competencies required in an innovation-driven global economy.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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