

Bridging Chemistry and Computing Science: Innovative Teaching Tools in Pre-service Teacher Education

Suthida Chamrat^{1*}, Surasak Maotheuak¹, Kittaporn Puakanokhirun¹, Theenawat Nanta¹, Nattaya Apichatyotin¹, Warissara Kraijitmate¹, and Pongsathorn Suyamool²

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Abstract

This study investigated integrating computing science into chemistry education for pre-service teachers, focusing on using microcontrollers like Micro:bit and Arduino to develop STEM-based chemistry lessons. It involved eight pre-service teachers selected via purposive and voluntary sampling methods, participating in a longitudinal exploration from 2017 to 2020. Data were collected through various methods on courses in a chemistry education program, encompassing lesson plans, artifacts, videos, and photographs, and they were analyzed through content analysis. The key findings encapsulate the essence and impact of this integration: (1) Micro:bit emerged as the primary microcontroller used by pre-service teachers; (2) Projects often centered around environmental issues; (3) Effective integration of computer programming into chemistry teaching necessitated support from computer specialists or programmers; (4) The creation of microcontroller-based sensors/projects significantly enhanced the incorporation of computing science within science lessons; (5) Initial endeavors in blending computing science into chemistry education led to a rich variety of activity designs and innovations; (6) The development and use of microcontroller-based sensors facilitated the execution of more complex experiments in chemistry education. These findings underscore the potential of an interdisciplinary approach in enriching STEM-oriented chemistry education, highlighting the importance of teacher competence, professional development, and integrative teaching methodologies. This research provides vital insights for future pedagogical strategies and underscores the value of incorporating computing science in science education.

Keyword: Computing Science; Microcontroller; STEM Education; Chemistry Education

¹ Department of Curriculum, Instruction & Learning, Faculty of Education, Chiang Mai University, Thailand

² Department of Vocational Education and Wellness Promotion, Faculty of Education, Chiang Mai University, Thailand

* Corresponding author e-mail: suthida.c@cmu.ac.th

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สุทธิดา จำรัส¹, สุระศักดิ์ เมาทือก¹, นฤตพร พัวกนกหัสิณ¹, ธีร์นวัช นันตา¹, นาฏญา อภิชาติโยธิน¹,
วริศรา ไกรจิตเมตต์¹ และ พงษ์ศร สุษะมูล²

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บทคัดย่อ

งานวิจัยในครั้งนี้ศึกษาการบูรณาการวิทยาการคำนวณเข้ากับการศึกษาเคมีสำหรับครูก่อนประจำการ โดยเน้นไปที่การใช้ไมโครคอนโทรลเลอร์ เช่น Micro:bit และ Arduino เพื่อพัฒนาบทเรียนเคมีที่ใช้แนวคิดสะเต็มเป็นฐาน กลุ่มที่ศึกษาเป็นครูก่อนประจำการ 8 คน ได้มาด้วยวิธีการเลือกแบบเจาะจงและสมัครใจเข้าร่วมการวิจัยด้วยวิธีศึกษาระยะยาว ตั้งแต่ปี พ.ศ. 2560-2563 การวิจัยมุ่งเน้นไปที่การใช้ไมโครคอนโทรลเลอร์ Micro:bit และ Arduino เพื่อสร้างบทเรียนเคมีที่ใช้แนวคิดสะเต็มเป็นฐาน ข้อมูลถูกรวบรวมผ่านกระบวนการวิชาที่สอนในหลักสูตรเคมีศึกษา ประกอบด้วย แผนการจัดการเรียน ชั้นงาน วิดีทัศน์และรูปภาพ วิเคราะห์ข้อมูลด้วยวิธีการวิเคราะห์เนื้อหา ข้อค้นพบสำคัญและผลกระทบจากกิจกรรมบูรณาการประกอบด้วย: (1) Micro:bit เป็นไมโครคอนโทรลเลอร์หลักที่ครูก่อนประจำการเลือกใช้; (2) โครงการส่วนใหญ่เน้นด้านสิ่งแวดล้อม; (3) การบูรณาการการเขียนโปรแกรมคอมพิวเตอร์เข้ากับการสอนเคมีอย่างมีประสิทธิภาพจำเป็นต้องได้รับการสนับสนุนจากผู้เชี่ยวชาญด้านคอมพิวเตอร์หรือโปรแกรมเมอร์ (4) การสร้างเซ็นเซอร์/โครงการที่ใช้ไมโครคอนโทรลเลอร์เป็นฐาน ช่วยยกระดับการบูรณาการวิทยาการคำนวณเข้าไปในบทเรียนวิทยาศาสตร์อย่างมีนัยสำคัญ (5) การเริ่มต้นที่จะพยายามนำวิทยาการคำนวณบูรณาการเข้ากับการศึกษาด้านเคมี นำไปสู่การออกแบบกิจกรรมและนวัตกรรมที่หลากหลาย (6) การพัฒนาและการใช้เซ็นเซอร์ที่ใช้ไมโครคอนโทรลเลอร์เป็นฐานช่วยให้การทดลองที่ซับซ้อนในวิชาเคมีสามารถดำเนินการได้อย่างสะดวกมากยิ่งขึ้น ข้อค้นพบนี้แสดงให้เห็นถึงศักยภาพแนวทางการบูรณาการวิทยาการคำนวณที่ส่งเสริม การจัดการ การศึกษาเคมีโดยใช้สะเต็มเป็นฐาน รวมทั้งแสดงให้เห็นถึงความสำคัญของสมรรถนะครู การพัฒนาครู ศาสตร์การสอนที่เน้นการบูรณาการข้ามสาขาวิชา และย้ำถึงคุณค่าของการนำวิทยาการคำนวณเชื่อมโยงไปยังวิทยาศาสตร์ศึกษา

คำสำคัญ: วิทยาการคำนวณ; ไมโครคอนโทรลเลอร์; สะเต็มศึกษา; เคมีศึกษา

¹ ภาควิชาหลักสูตร การสอนและการเรียนรู้, คณะศึกษาศาสตร์, มหาวิทยาลัยเชียงใหม่

² ภาควิชาอาชีวศึกษาและการส่งเสริมสุขภาพ, คณะศึกษาศาสตร์, มหาวิทยาลัยเชียงใหม่

* Corresponding author e-mail: suthida.c@cmu.ac.th

Introduction

The world in the digital era needs humans to have higher-order thinking in integrative ways (Conklin, 2011). This need arises from our encounter with the VUCA (Volatility, Uncertainty, Complexity, and Ambiguity) world (Bennett & Lemoine, 2014). Problems in the modern world tend to be ill-defined and need complex problem-solving skills. A single discipline is not capable of coping with the encountered challenges, for example, climate change, world pandemics, and world trade war. A discipline that has a long history, like chemistry, is not new for integration with other disciplines. The Ministry of Education (2017) in Thailand introduced a new subject within the fourth strand, titled "Computing Science". This strand focuses on teaching students computational thinking, providing them with foundational knowledge in digital technology, and equipping them with media and information literacy skills.

Although Computing Science is a recent addition to the core curriculum, its concepts and methodologies have a longstanding history in the field of chemistry. Chemists use programming languages to study, model, and predict molecular structures (Dong et al., 2015). Computer models of chemical structures are useful for observing chemical reactions prior to actual synthesis in the laboratory. Chemical instrumentation and analytical chemistry are also branches of chemistry that heavily need computer literacy and computational thinking skills. Furthermore, in theoretical and computational chemistry, chemists use and develop sophisticated mathematical and computational algorithms to study chemical processes (Weintrop et al., 2016).

The integration of computing science into chemistry education reflects these aspects of the nature of chemistry, especially in chemistry teacher programs. However, research and rigorous examples of integrating computing science into chemistry classrooms are not widely available (Wangsalae & Swengam, 2021). The current indicators and core concepts in a science subject, as per the revision in B.E. 2560, following the basic education core curriculum B.E. 2551 (Wangsalae & Swengam, 2021), emphasized the integration of computing science into other science strands, including physical science, biological science, earth, and space science. In the Chemistry strand, the learning indicator indicated that grade-12 students must

“Provide evidence of the integration of chemistry into other disciplines, including scientific process skills or engineering design process that address analytic thinking, problem-solving, and creative thinking for problematic situations or interesting issues”

To achieve this, prospective chemistry teachers should gain experience in designing and developing chemistry classrooms that integrate computing science with other STEM

disciplines. This current study investigates and explores how pre-service teachers design and develop STEM-based chemistry lessons that incorporate computing science. In doing so, it identifies at least three obstacles hindering the integration of computing science in chemistry: (1) Pre-service teachers often do not recognize or are unaware of the role that computing science can play in chemistry. They tend to view chemistry as a content-led discipline and detach it from its context (Faikhamta, Ketsing, Tanak, & Chamrat, 2018). (2) There is a lack of understanding the nature of scientific knowledge, computing science, and computational chemistry (Rodríguez-Becerra et al., 2020), despite their important roles in the development of science and chemistry knowledge. (3) Since the introduction of computing science and computational thinking into Thailand's core curriculum in 2017 (Ministry of Education, 2017), there has been a notable lack of research in these areas, underscoring the need for more focused studies in this field. Even though pre-service teachers are aware of and value the integration of computing science in chemistry, they struggle to overcome the initial phase of the learning curve.

The findings illustrate the characteristics of how four years of effort can initiate and sustain the integration of computing science into chemistry education courses. This is evidenced by the success of some pre-service teachers who were able to disseminate their work in national-level research publications, present at international conferences on STEM education, and showcase their projects in nationwide workshops held by the Thai Digital Economy Promotion Agency (depa) between 2020-2022. The key findings highlight potential methods for integrating computing science into STEM-based chemistry classrooms. The discussion points toward future research areas, such as teacher competency, teacher professional development, and integrative approaches in science teacher education.

Research Objectives

This longitudinal study of learning activities from 2017 to 2020 aimed to

1. Investigate the methods and impacts of integrating computing science into chemistry education.
2. Identify the key factors, strategies, and challenges in incorporating computing science into chemistry teaching, specifically focusing on the use of microcontrollers, thematic projects, the necessity for specialist oversight, and the design and execution of complex experiments.

Literature Review

Chemistry education extends beyond the simple impartation of chemical principles; it aims to equip students with the necessary tools to apply these principles across diverse contexts. In this regard, microcontrollers have been demonstrated as effective learning tools, particularly in computer science education, where they provide practical insights into programming, hardware-software interaction, and embedded systems (Mabbott, 2014). Similarly, computational thinking is a critical tool in education, aiding students in formulating and solving problems that computers can effectively address. It leverages techniques such as abstraction, automation, and analysis (Weintrop et al., 2016). Within this framework, project-based learning offers an authentic context, wherein students engage in extended periods of inquiry in response to complex real-world problems. This approach effectively consolidates their knowledge and skills (Diawati, Liliyasi, Setiabudi, & Buchari, 2018). Such a learning approach is particularly beneficial in STEM-based chemistry classrooms for pre-service teachers. It equips them with the essential skills and knowledge required to teach chemistry effectively, utilizing an integrative approach that combines principles of science, technology, engineering, and mathematics (Blikstein, 2018). Existing research on integrating STEM and computing science in chemistry education demonstrates a diverse and innovative approach toward enhancing teaching methodologies and student learning outcomes. The study by Pewkam and Chamrat (2022) exemplifies this, focusing on developing computational thinking skills in pre-service teachers through a STEM-based activity – the Computing Science Teacher Training (CSTT) program in Thailand. This program emphasizes the integration of computing science, which has been mandatory in the Thai science curriculum since 2018. This approach reflects the global educational trend of blending computational thinking with traditional disciplines to create a more holistic and interdisciplinary learning environment.

Complementing this trend, other research works have made significant contributions. For instance, Sengupta, Kinnebrew, Basu, Biswas, and Clark (2013) advocated for a phenomenological approach to computational thinking in STEM education, suggesting that it encompasses computational logic, discursive, perspectival, material, and embodied aspects. Oteri (2021) explored the use of microcontroller-based mobile labs in various learning settings, highlighting the adaptability and continuity of STEM education amidst disruptions like the COVID-19 pandemic.

Diverging slightly, Swaid (2015) discussed the incorporation of Computational Thinking into STEM disciplines at the undergraduate level, emphasizing the necessity for STEM educators to adapt to advanced technologies and cloud computing tools.

Lee, Grover, Martin, Pillai, and Malyn-Smith (2020) examined the integration of computational thinking in K-12 STEM education, focusing on the challenges and potential strategies for better alignment with disciplinary practices. Moreover, Koçak, Çelik, and Uluyol (2023) investigated the impact of STEM-based environmental education with microcontroller integration on pre-service teachers' environmental literacy, thereby demonstrating the effectiveness of STEM-oriented education in enhancing understanding of environmental issues. Together, these studies illustrate a significant shift in STEM education towards incorporating computational and digital competencies, underscoring the evolving landscape of chemistry education in the age of digital technology.

Research Conceptual Framework

The conceptual framework for this research can be visualized as a diagram that effectively illustrates the interconnectedness of the major concepts. This diagram represents how Chemistry Education can utilize STEM-based principles to create a STEM-based Chemistry Classroom. This classroom uses microcontrollers as learning tools, computational thinking as thinking tools, and project-based learning as learning context, as follows:

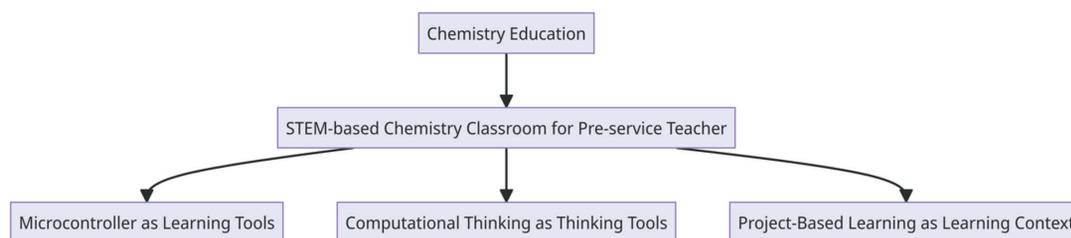


Figure 1 Research conceptual framework

This framework is designed specifically to guide the integration of computing science into a STEM-based chemistry classroom for pre-service teachers. It outlines the use of microcontrollers, computational thinking, and project-based learning as pivotal tools for this integration. At the same time, the framework serves as a foundation for the activities within the classroom.

Methodology

This study employs a qualitative, longitudinal approach to examine the feasibility and degree of integration of computing science into STEM-based chemistry education for pre-service teachers. The details of the methodology employed are presented below.

Research participants

Eight pre-service teachers were selected to participate in this study through

purposive sampling. The selection criteria included those who were enrolled in a Bachelor of Chemistry Education program and who had voluntarily participated in a computing science project. Participants were from various academic levels, including sophomores, juniors, and seniors, spanning the academic years from 2017 to 2020, who studied in Chemistry Education program. The STEM-based chemistry activities in which they engaged were part of the methodological courses within a five-year Chemistry Education program. Data collection included pre-service teachers' project work, lesson plans, project reports, and various artifacts. Additionally, photographs and videos taken during the presentations of processes and final products were collected with consent. To maintain confidentiality, all images and footage featuring students were appropriately censored to protect their identities.

The Integration of Computing Science

There are various forms of integrating computing science into chemistry classrooms. This study encouraged pre-service teachers to design and develop two types of integrative computing science activities: a learning activity and a STEM project, both utilizing microcontrollers, computational thinking, and project-based learning as key tools for integration. In the learning activity, pre-service teachers developed educational materials using microcontrollers to design DIY sensor functions. They also created lesson plans incorporating these DIY sensors in chemistry classrooms, implementing the lessons with their peers in method courses. The second type, the STEM project, involved pre-service teachers identifying problematic situations or interesting issues and inventing STEM equipment as solutions to these problems. Both types of computing science integration were based on the learning indicators and core concepts of computing science, as outlined in the science subject revision B.E. 2560, following the basic education core curriculum B.E. 2551, which emphasizes applying computational thinking to develop projects that integrate creatively with other disciplines and are relevant to real life (Ministry of Education, 2017).

Data collection and analysis

The data were collected from pre-service teachers' project reports, microcontroller kits, and project products. A longitudinal research methodology was employed to scrutinize various methods courses within a chemistry education program. The projects, developed between 2017 and 2020, spanned across three courses:

064417 Independent Study: Pre-service teachers selected topics of interest within the scope of science and chemistry, aligning with the core concepts and indicators outlined in the science subject curriculum (revision B.E. 2560) according to the basic education core curriculum B.E. 2551 (Ministry of Education, 2017).

064413 Bodies of Science Knowledge Instruction on Chemistry Contents: This course focused on an in-depth exploration of chemistry subject matter, ensuring a comprehensive understanding and application of key concepts.

064490 Equipment, Chemicals and Experiment in Chemistry Laboratory: The emphasis here was on the practical use and development of laboratory equipment, enhancing hands-on skills in conducting chemical experiments and managing laboratory resources effectively.

Each pre-service teacher chose to undertake projects individually as part of their course assignments. A total of 8 pre-service teachers developed three lessons and seven projects that integrated computing science into STEM-based chemistry classrooms. The titles of these ten projects are shown in Table 1. All data, including the three lessons and seven projects, were labeled, coded, and grouped into categories using the process outlined in the content analysis guidebook by Neuendorf (2018). This process began with (1) reviewing the literature, theories, and rationales, (2) making conceptualization decisions, (3) operationalizing the coding scheme relevant to the research objectives, (4) employing human-computer coding – the researcher read through all data and coded it with the assistance of the data analysis software ATLAS.ti, and (5) grouping codes into code families, categories, and themes. A total of 60 codes from 14 code groups emerged from the data analysis. Six themes that will be discussed in the next section emerged. The data were also presented using Scimago Graphics for data visualization.

Results and Discussion

From the content analysis that searched for themes by comparison and combining codes, six thematic results emerged as follows.

Theme 1 Micro:bit and Arduino were the microcontrollers that was used by pre-service teachers

Pre-service teachers have a range of choices regarding the equipment they use in their projects or learning activities. Micro:bit and Arduino have become the most common microcontrollers used by pre-service teachers, as indicated in Table I. This preference is due to the accessibility and affordability of these tools. The availability of digital technology is a key driver of the digital movement in education. The dramatic cost reduction in technologies closely related to fabrication and making has made the integration of computing science more feasible, as highlighted by Blikstein (2018). Micro:bit, a low-cost computer board, was distributed to thousands of seventh graders by the BBC in England, along with curricula and several programming environments. In Thailand, Micro:bit, along with Arduino, KidBright, etc., are used at the basic education level.

The programming platform is available on makecode.com, where the interface of Makecode.com provides both block-based coding and text coding.

Table 1 Stem learning activities and STEM projects developed by pre-service teachers

Project	Title	Type	Microcontroller
1	Water quality in various sources in the university	Science Learning Activity	Arduino
2	The design and development of home air purifier by the integration of computing science in steam education	STEM Project	Micro:bit
3	Feeding the automation system by microcontroller-based equipment for chemical mixing	STEM Project	Arduino
4	The use of Micro:bit to investigate the effect of light intensity and temperature on plant transpiration	STEM Project	Micro:bit
5	The development of learning material using a micro:bit to investigate the gas law	STEM Project	Micro:bit
6	Coding in the science classroom: the use of Micro:bit as a learning tool for land breeze and sea breeze concepts	STEM Project	Micro:bit
7	Learning moon phases by the integration of computing science	STEM Learning Activity	Micro:bit
8	The Carbon monoxide sensor to study the effectiveness of an internal combustion engine	STEM Learning Activity	Arduino
9	The development of DIY gas laws experiment set using computing science	STEM Project	Arduino
10	The Applications of Microcontroller for the invention of digital pH meter	STEM Project	Arduino

Arduino was the first microcontroller that Ice (pre-service teacher's synonym) chose for the science learning activity in the method course. The project was directly adopted from the Microsoft Learn Educator Center: Hacking STEM (Microsoft Learn Educator Center, 2023). However, choosing Arduino presented Ice with barriers due to the learning curve, akin to the findings of Rivers, Harpstead, & Koedinger (2016), as Ice was new to microcontrollers. Some studies have pointed out limitations of Arduino boards. For instance, Scolnic (2015) argued that Arduino's traditional text-based programming language, based on C++, can be challenging for those inexperienced or new to Arduino. As a result, pre-service teachers in subsequent projects opted for Micro:bit instead.

Given that the order of projects from 1-10 was chronological, Fig. 2 shows a Sankey chart visualizing the sequence of projects over time and the microcontrollers chosen by the students for their projects.

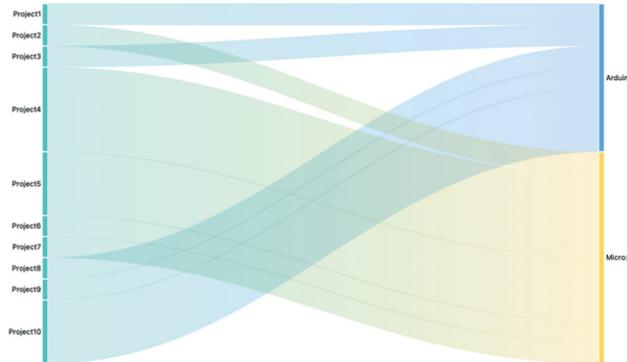


Figure 2 Sankey chart of projects and chosen microcontroller order by time

Initially, the students chose Arduino as their tool of choice due to its popularity and availability. However, they faced limitations owing to their lack of proficiency in text-based programming. Consequently, they transitioned to the block-based programming provided by Micro:bit for projects 2, 4, 5, and 7. Following these projects, they returned to using Arduino. This shift was influenced by the guidance of a computer specialist as their supervisor and their improved coding skills over time.

Theme 2 Environmental issues are prevalent projects

The environment emerged as the main issue that pre-service teachers addressed in STEM learning activities and projects. Scientific inquiries focused on students’ local environments have been reported as successful in terms of engagement and empowerment (Honma, 2017). In this research, the first pre-service teacher who investigated the quality of water around the university achieved notable success in garnering attention from her students. The water samples collected from the campus reservoir, nearby ponds, and university drinking water sources captivated interest, in addition to the novel technique of using a microcontroller and a sensor.

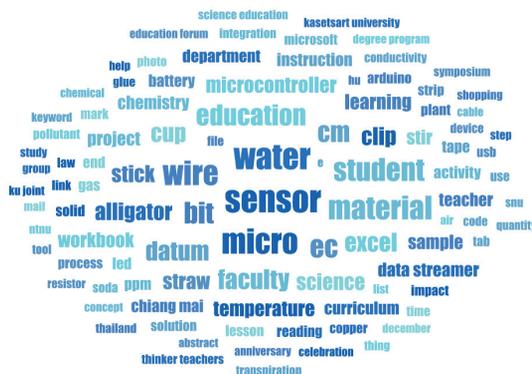


Figure 3 The Word Cloud visually highlights key concepts from ten projects, with word size indicating frequency or importance.

Word Cloud from the ten project reports indicated that 'sensor development,' 'water measurement,' and 'Micro:bit' were the most frequently appearing words in the integration of computing science in chemistry classrooms in this study.

Theme 3 The integration of computer programming needed supervision by computer specialists or programmers

Arduino was used in the initial phase of introducing computing science into chemistry classes. However, programming Arduino required at least basic computer programming skills. Consequently, Micro:bit became the preferred choice for pre-service teachers in later projects. Nonetheless, some projects demanded more sophisticated programming due to multiple variables. In these cases, pre-service teachers needed supervision from computer specialists or programmers. Pre-service teachers in Science or Chemistry education programs were not trained to be computer teachers, necessitating collaborative work with others. Working on these projects reflected the nature of STEM, requiring the integration of knowledge and skills from different disciplines. As Isaacson (2014) noted, the success of digital transformation and innovation is usually achieved by groups with diverse talents, with few innovations resulting from individual efforts alone.

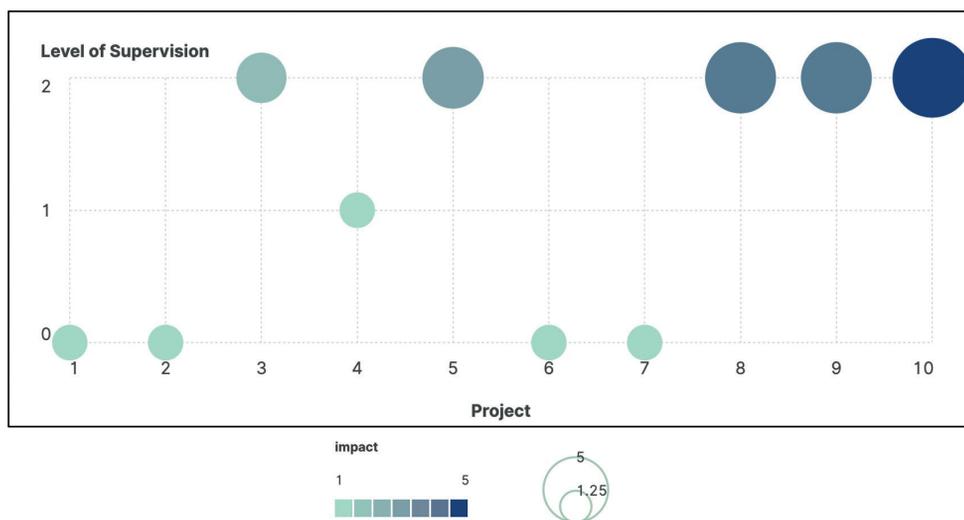


Figure 4 Level of supervision and its impact on project distribution and success

Figure 4 provides a compelling depiction of the level of supervision in various projects and their corresponding impacts. It uses a numerical scale where 0 indicates a project that has not been distributed, 1 represents a project shared at a local level, and 2 signifies a project that has achieved national recognition or been published in a national Thai-Journal Citation Index (TCI). Higher values on this scale denote a greater extent of distribution and impact, highlighting the success of those projects. Projects rated '2' have

not only made a significant local impact but have also contributed to national discourse, demonstrating their value and efficacy. The visual representation in Figure 4 thus underscores the correlation between the level of supervision, distribution, and overall success of the projects.

Theme 4 The invention of microcontroller-based sensors/projects supported the design and development of computing science integration into science lessons.

Since science indicators and core concepts require students to understand and execute STEM projects integrating technology and engineering with science and mathematics, a direct and effective approach was using microcontrollers to invent scientific equipment, such as water or gas sensors. This study found that, following the creation of these devices, pre-service teachers could develop and design science/chemistry lessons based on their projects. The invention process necessitated a deep understanding of both science concepts and their practical applications. These findings align with the principles of constructionism. Pre-service teachers learned to design and develop science/chemistry lessons by engaging in the process of invention, paralleling Seymour Papert's concept that learning is enhanced when individuals create tangible objects in the world (Harel & Papert, 1991).

Theme 5 The experiences of the integration of computing science into the chemistry classroom in the first place, lead to other chemistry activity designs and developments.

This theme emerged from the case profile of Orn, a pseudonym used here. She first became involved in the project as a sophomore. Her initial project focused on teaching and learning about the Moon phases using multiple representations. She employed various hands-on analogies in her class and used Micro:bit to create models of the Moon phases. Students in her class utilized [Makecode.microbit.org/](https://makecode.microbit.org/) to display representations of the eight moon phases through the 'show LEDs' function: New Moon, Waxing Crescent, First Quarter, Waxing Gibbous, Full Moon, Waning Gibbous, Last Quarter, and Waning Crescent. Following this, Orn developed another chemistry activity using Micro:bit with a Carbon monoxide gas sensor extension. Her most recent project, 'The Development of DIY Gas Laws Experiment Set using Computing Science,' employed Arduino instead of Micro:bit. This time, the project was under the supervision of a computing science teacher, recognized as a computer specialist. Orn's case illustrates that, within a supportive environment, pre-service teachers can develop their skills in coding, programming, and the competency of designing and developing integrative chemistry activities. Continuously engaging in invention gradually fosters a maker mindset, contributing to the broader maker movement (Bevan, 2017) teachers in designing

and developing STEM teaching and learning environments (Chamrat, 2019). The findings suggest that pre-service teachers with considerable experience in incorporating computer science into chemistry education are likely to excel in lesson planning and development. As shown in Figure 5, Orn serves as a notable example, having independently developed three projects. She began with a STEM project and then autonomously created two additional STEM learning activities.

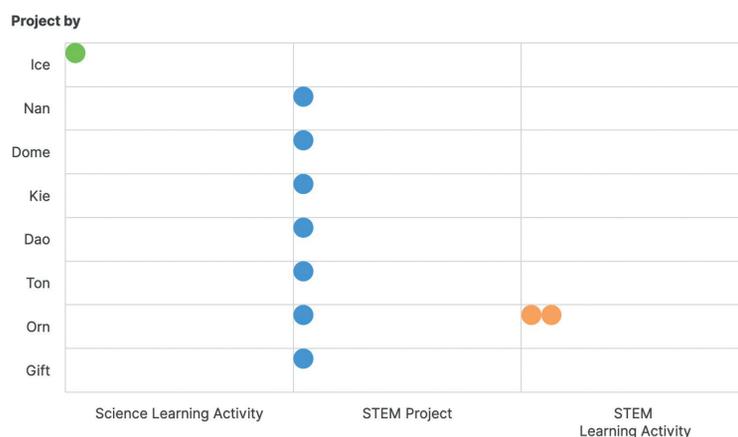


Figure 5 Classification of pre-service teacher projects: from science learning activities to STEM projects and activities in a chemistry classroom

Studying computing science can help a chemistry teacher enhance their lesson design and development. For example, computing science principles can be applied to lesson planning. Concepts such as algorithms, data structures, and programming languages can be utilized to create interactive and engaging lesson plans, aiding students (pre-service chemistry teachers' students) in grasping complex chemical concepts.

As technology skills become increasingly vital in the classroom, a computing science background equips chemistry teachers with the necessary skills and knowledge to integrate technology into their lessons. This includes the use of simulations and visualizations to facilitate students' understanding of chemical reactions and phenomena.

In chemistry education, the analysis and interpretation of experimental and simulation data is critical. Incorporating computing science into the curriculum of pre-service chemistry teachers enhances their ability to use analytical and visualization tools, such as Excel and Python. This proficiency enriches lesson development and delivery, making teaching more dynamic and effective, and prepares educators to integrate technology and data analysis seamlessly into their pedagogical practices. These findings are in line with Bevan (2017), highlighting the significant role of computing science in enriching chemistry education.

Theme 6 The design and development of microcontroller-based sensors could fill the gap, making experiments such as gas law and gas detector easier to implement

Out of ten projects, seven involved measurements of water or gas. Conducting experiments that involve gas collection using DIY equipment, as experienced by eight pre-service teachers, represents a novel approach not previously undertaken in standard basic education chemistry classrooms. The limitations in accessibility and availability of scientific equipment are significant factors. Considering the opportunity to conduct measurements and typically challenging experiments, the integration of computing science opens new possibilities for teachers and students. DIY low-cost scientific equipment, developed using microcontrollers and sensors, can lead to more equitable science learning. In recent years, the rapidly spreading maker culture and online commerce platforms have facilitated access to low-cost sensors and microcontrollers (Blikstein, 2018). Pre-service teachers can purchase gas or pH sensors online at a cost of only 1-3 US dollars. This rise of the maker movement has the potential to bridge the gap in educational equality, as Honma (2017) suggested.

Conclusion and Recommendation

Research results indicate feasible methods for explicitly integrating computing science concepts and practices into chemistry classrooms. The availability of accessible equipment like microcontrollers and extensions makes this integration more practical. Regarding classroom implications, the research suggests (1) starting with easy-to-use boards like Micro:bit; (2) initiating learning or project contexts with familiar environments, such as schools or local areas; (3) collaborating with programming specialists or programmers when using more sophisticated microcontrollers that require computer programming skills; (4) employing the invention of microcontroller-based sensors/products to support the design and development of computing science integration into science lessons, as this process requires pre-service teachers to understand STEM concepts and practices deeply; (5) noting that initial experiences of integrating computing science into the chemistry classroom lead to further chemistry activity designs and developments; and (6) recognizing that the design and development of microcontroller-based sensors can bridge the gap in experiments that are challenging to conduct, such as those involving gas laws and gas detection.

The findings also showcased potential methods for integrating computer science into STEM-based chemistry classrooms, similar to the approach described by Mabbott (2014). These findings will guide future research, such as exploring teacher competency, professional development, and integrative methods in science teacher education.

In conclusion, incorporating computing science into STEM and chemistry education through practical, contextual, and team-based approaches can significantly transform classroom dynamics. This method fosters a culture of exploration and creativity, leading to a more comprehensive understanding of STEM subjects. These results provide valuable insights for educators, policymakers, and curriculum designers focused on enhancing learning experiences.

Regarding implications for future research, the results highlight a connection between the design and development of microcontroller-based experiment sets and the design and development of science/chemistry learning activities. An emerging research question is how and to what extent DIY sensors/projects can enhance pre-service teachers' ability to design and implement science lessons. The outcomes of both current and future research will reinforce the effectiveness of science teacher education programs and professional development initiatives.

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