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Effects of small-scale chemistry STEM integrated with local contexts for enhancing grade 11 students' learning achievement and learning and innovation skills

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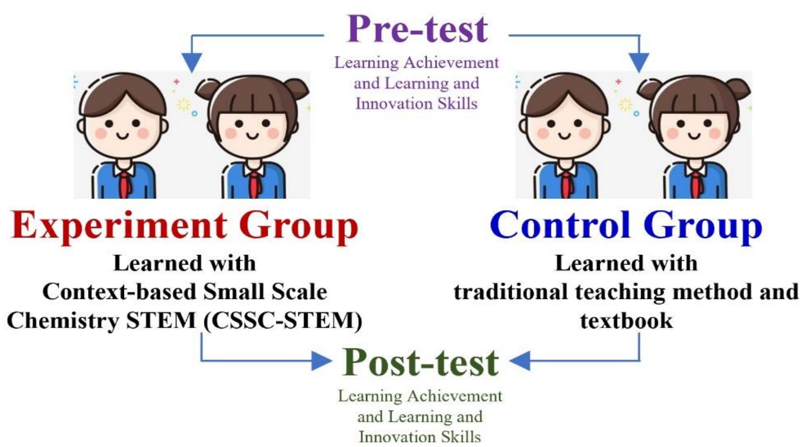
Abstract

This study aimed to; a) create the context-based small-scale chemistry STEM (CSSC-STEM) Model; and b) examine the effects of the CSSC-STEM model on students' learning achievements and learning and innovation skills. The research methodology was Research and Development (R&D). In R1D1, 60 chemistry teachers and 136 students responded to reflect problems and needs about teaching and learning chemistry. In R2D2, 43 and 41 Grade 11 students were in an experiment and control groups, respectively. In R3D3, 40 and 36 students were in the experiment and control groups, respectively. The results showed that the experiment group had higher learning achievement in Rate of Chemical Reactions ($t = 7.599$, $p < 0.05$) than the control group. In addition, the experimental group had higher critical problem-solving skills ($t = 20.968$, $p < 0.05$) and creative thinking skills ($t = 23.168$, $p < 0.05$) than control group. The experiment group also gradually improved communication and teamwork skills throughout the model. The R3D3 results aligned with R2D2 showing the reliability of the CSSC-STEM model.



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Highlights

- CSSC-STEM is a new model.
- CSSC-STEM enhanced student learning and innovation skills.

CONTENTS

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1. Introduction

From the past to the present, science has held a pivotal role in our societies, encompassing various aspects of our everyday lives. The synergy between scientific advancement and human creativity has led to the emergence of technologies that enhance our efficiency and effectiveness in both our personal and professional endeavors. The body of scientific knowledge equips individuals with a heightened understanding of natural phenomena, fostering greater awareness. Furthermore, the scientific process fosters the development of diverse cognitive skills such as logical, creative, analytical, and critical thinking, while also nurturing practical proficiencies including problem-solving, inquiry, and decision-making capabilities.

Science plays a crucial role, particularly in enhancing our capacity to make well-informed decisions grounded in reliable and empirical evidence. It contributes to the formation of a modern societal culture referred to as the "Knowledge-based Society". Given the paramount significance of science as highlighted earlier, it is imperative that everyone strives to become scientifically literate. A scientifically literate individual not only possesses foundational scientific knowledge about natural phenomena and human-made technologies but also can logically and ethically apply this scientific knowledge to their everyday life, thus enabling them to navigate the complexities of the world. These attributes of scientific literacy within individuals contribute to the responsible application, sustainable upkeep, and progressive development of both the natural environment and its resources. This comprehensive perspective nurtures a harmonious and enduring coexistence with our environment (Institute for the Promotioin for Promotion of Teaching Science and Technology (Chanprasert, 2014)).

The paramount importance of science accentuates the crucial need for effective science education. However, the process of teaching and learning science in Thailand is still confronted by various difficulties and obstacles. The results of the Ordinary National Education Test (O-NET) in Grades 10-12 science subjects throughout the academic years of 2014-2016 remained persistently below the expected threshold, registering at 32.54%, 33.40%, and 31.62% respectively, all falling short of the established standard (National Institute of Educational Testing Service (Public Organization) (NIETS), 2017). The National Education Plan B.E. 2560-2579 (A.D. 2017-2036) further highlights the ongoing dissatisfaction with the outcomes of educational advancement, given that students' learning achievements continue to fall below both established standards and the performance of other Asian countries. Despite a growing inclination among students to seek out additional knowledge, there remains a deficit in their capacity to effectively organize and synthesize the gathered information (Office of the Education Council (ONEC), 2002). Relying solely on lecture-based instruction might prove inadequate in enabling students to fully grasp the intended subject matter, potentially resulting in both inadequate content acquisition and a sense of disinterest towards science learning (Passakchai and Kuno, 2015). This, in turn, can contribute to a diminished enthusiasm for pursuing further studies in the domains of science and mathematics.

The aforementioned phenomenon highlights an issue within science education in schools, potentially resulting in a deficiency of motivation for students to engage in science learning. Additionally, this situation can hinder the establishment of connections between scientific knowledge and its practical applications in daily life, as well as its relevance to future pursuits and careers. Hence, the Ministry of Education is actively engaged in revising the Basic Education Core Curriculum, with the aim of aligning it more effectively with the development and preparation of students as valuable human resources for the 21st-century global landscape. The focus lies in fostering a meaningful comprehension of science among students while nurturing the essential 21st-century skills vital for both their personal and professional lives.

To achieve these objectives and enhance the country's competitiveness in the face of evolving science and technology, an integrative curriculum has been proposed. This curriculum, designed to span both individual subjects and their intersections, presents a strategic solution for addressing the aforementioned goals (Ministry of Education, 2017). One of the prominent approaches within the integrative curriculum is STEM (Science, Technology, Engineering, and Mathematics) education. Various studies indicate that STEM education has demonstrated a notable enhancement in students' learning achievements when compared to conventional teacher manual-based teaching approaches (Khammamung, 2017; Wicheansang *et al*., 2018; Khonchaiyapham, 2017; Poonruang, 2016; Saengpromsri, 2015). Consequently, an imperative step is to encourage science educators to embrace and implement STEM education not only in the realm of teaching science but also in related subjects.

Numerous research studies corroborate the assertion that STEM education ignites a heightened enthusiasm for learning, fostering a willingness to tackle challenges, and bolstering students' self-assurance as they engage with science at advanced levels and in subsequent educational endeavors (Pornthip Siripithrachai, 2017: 50). Notably, Khammamung (2017) examined the impact of STEM education on Grade 10 students' comprehension and critical thinking in the context of chemistry reactions was examined. Her findings unveiled that STEM education contributed to a heightened eagerness for learning and facilitated the interlinking of science, technology, engineering, and mathematics knowledge. Additionally, students demonstrated increased engagement with the subject matter and a propensity for collaborative work within groups. This approach resulted in a statistically significant elevation in students' learning achievement and critical thinking skills at a level of significance of .01. Furthermore, Poonruang (2016) found that Grade 11 students, upon exposure to STEM education, exhibited greater advancements in learning achievement and problem-solving prowess within the realm of chemical life topics, compared to their previous achievements at a .05 statistical significance level. Additionally, STEM education was instrumental in elevating Grade 11 students' learning achievement, science process skills, and positive attitudes toward learning chemistry to a level significantly surpassing the outcomes of traditional teaching methods (Saengpromsri, 2015). Furthermore, in the research by Ketsrisakda *et al*. (2017), the experiment group of students who received instruction through STEM education demonstrated superior learning achievement compared to their previous levels at a 0.05 statistical significance level. Importantly, the same experiment group outperformed the control group, which was taught through conventional methods, in terms of learning achievement, also reaching a 0.05 statistical significance level.

Among the myriad skills encompassed by the 21st-century repertoire, learning and innovation skills take a pivotal stance for students in this era, as these proficiencies prove essential for navigating the complexities of contemporary lives and future careers. The evolving landscape demands a skill set that transcends the conventional, an exigency aptly addressed by learning and innovation skills. Nevertheless, the revelations drawn from the ONET (Ordinary National Education Test), and PISA (Programme for International Student Assessment) assessments of Thai students highlight a concerning trend. Students' ONET scores manifest a deficiency, while their PISA scores left behind those of other countries with similar Gross Domestic Product (GDP) standings (National Education Plan B.E. 2560-2579 (A.D. 2017-2036). The roots of these challenges are multi-fold. One significant contributor lies in the students' disproportionate focus on university entry facilitated by tutoring, which might inadvertently undermine self-regulated learning, problem-solving capabilities, as well as communication and creativity skills. The curriculum and learning systems also merit scrutiny, as they tend to disproportionately emphasize content absorption and the rote memorization of information. Consequently, this emphasis tends to overlook the holistic development of skills. The result is a student body lacking proficiencies in creative thinking, innovative approaches, analytical and synthetic reasoning, and effective learning strategies. A noteworthy contributing factor lies in the students' disproportionate concentration on university admission, often facilitated by tutoring, inadvertently eroding their self-regulated learning, problem-solving abilities, and even communication and creativity skills. Moreover, the scrutiny of curricula and learning systems is warranted, as they tend to place undue emphasis on mere content assimilation and rote memorization. Consequently, this emphasis undermines the comprehensive development of skills. The outcome is a student populace deficient in essential proficiencies, encompassing creative thinking, innovative approaches, analytical and synthetic reasoning, as well as effective learning strategies (Chulawattanatol, 2013).

Penratanahiran and Thongkham (2011) explored the challenges faced by primary school students in relation to the 4Cs: Critical thinking, Communication, Collaboration, and Creativity. The findings illuminated several areas of concern. Specifically, in the domain of Critical thinking, it was evident that students displayed shortcomings in observation and problem-solving skills. Their grasp of analytical, logical, and critical thinking was also deficient. This deficiency was exemplified by students' inability to assess the reliability of data sources and their tendency to overlook the search for pertinent information, thus culminating in decisions that were not well informed. Furthermore, the students demonstrated a lack of proficiency in systematic problem planning and resolution, as well as an inability to conceive fresh approaches when addressing the challenges at hand.

In terms of Communication, a notable deficiency was observed among students, particularly in their understanding and practical application of effective communication techniques. They exhibited challenges in employing suitable language for reading, writing, and speaking contexts. Furthermore, they struggled with competently receiving and comprehending the nuances of conveyed messages. A distinct lack of self-assuredness was evident when expressing themselves to others, notably during classroom presentations. Moreover, it was apparent that students sometimes intertwined their viewpoints with factual data, inadvertently leading to misunderstandings among their audience about the intended message.

In the realm of Collaboration, students displayed a tendency towards self-centeredness, often at the expense of acknowledging and respecting their peers' opinions and capabilities. Their capacity to engage effectively in group dynamics was notably compromised. They struggled when it came to cooperative endeavors such as joint planning, decision-making, and task execution within teams. While a subset of students exhibited some proficiency in teamwork, their ability to adapt or seamlessly transition into diverse situations or groups remained a challenge. Additionally, certain students encountered communication barriers stemming from differences in racial backgrounds and languages, further complicating the collaborative process. Additionally, certain students encountered communication barriers stemming from differences in racial backgrounds and languages, further complicating the collaborative process.

Addressing creativity, a prevalent trend was the students' deficiency in generating novel ideas, which often stemmed from their limited reservoir of supporting knowledge and experiences. Furthermore, they exhibited an insufficiency in self-efficacy related to creative thinking, frequently experiencing uncertainty due to their perceived inadequacy and apprehensions about encountering failure. The classroom environment, largely characterized by its teacher-centric nature, also exerted an influence on students' creative tendencies. In such settings, students frequently awaited instructions from the teacher instead of independently contemplating solutions. Consequently, students often retreated to the safety of their comfort zones, foregoing ventures into imaginative and creative thinking. This inadvertently hindered their capacity to think outside the conventional framework and inhibited the demonstration of their creativity and innovative ideas.

In the present era, our society is undergoing profound and constant transformations, primarily driven by the rapid progress of information and communication technology. This advancement has catalyzed the swift dissemination of new information and knowledge on a global scale. Consequently, a significant responsibility rests upon the government's shoulders: that of nurturing a human resource equipped with the vital 21st-century skills, essential for thriving in an ever-evolving landscape. Recognized as a potent pedagogical approach, STEM education has garnered widespread acceptance for its capacity to cultivate the 21st-century skills among students (Gonzalez and Kuenzi, 2012; Samahito, 2014; Siriphatrachai, 2013; Chulawattanatol, 2013; Seneewong, 2013; Acharry, 2019; Chanprasert, 2014).

In Thailand, STEM education has gained prominent recognition as a pedagogical approach integral to preparing young Thais for the future. Since 2013, it has been progressively integrated into science education across the nation (Siriphatrachai, 2013). STEM education is centered on fostering a cohesive approach to teaching, amalgamating the disciplines of Science, Technology, Engineering, and Mathematics. Students engaged in STEM education are proactively encouraged to tackle real-world challenges, applying the engineering design process to create innovative solutions and construct knowledge autonomously (Pudcha, 2016).

The essence of STEM education lies in nurturing an active and inquisitive mindset within students, emboldening them to embrace challenges and cultivate the self-assurance required to pursue advanced scientific learning (Siriphatrachai, 2013). As an educational paradigm, STEM education stands as a catalyst for the development of creative thinking, higher-order cognition, and 21st-century skills (Chanprasert, 2014). The implementation of STEM education commences by immersing students in locally relevant issues they are familiar with. This approach allows for the construction of new knowledge by challenging existing perspectives and prior experiences. Moreover, it empowers students to seamlessly integrate newfound knowledge into their daily lives, thus imparting a profound sense of meaning to their learning.

Regarding the teaching and learning of chemistry within the educational context of Thailand, a prevalent issue persists in most chemistry classrooms concerning laboratory activities. This predicament stems from the scarcity of laboratory equipment and the overwhelming student-to-classroom ratio. With laboratory resources often only accommodating two to three student groups, the limitations in equipment hinder the practical aspect of learning. In response, educators commonly resort to demonstrations and lectures to convey laboratory concepts. Regrettably, this approach gives rise to subsequent complications, notably a deficiency in students' hands-on experience with chemistry experiments and a lack of proficiency in scientific processes. Additionally, the majority of chemistry experiments featured in textbooks adhere to traditional methodologies, emphasizing stringent procedures to save time during experimentation.

A solution to this challenge emerges in the form of Small-Scale Chemistry (SSC) (Tamuang *et al.*, 2017), a novel approach to conducting chemistry experiments. SSC offers several advantages, primarily centered around safety, cost-effectiveness, convenience, and efficiency. By utilizing smaller quantities of chemicals and repurposing containers, SSC utilizes familiar substances and materials drawn from students' daily lives. This approach also minimizes the exposure to hazardous chemicals like acids and bases, subsequently reducing the potential risks associated with their usage. Notably, SSC enables teachers to better manage situations involving potential chemical leaks, given the diminished quantities employed. Embracing SSC empowers chemistry educators with heightened control over laboratory proceedings, cultivating an environment that seamlessly combines efficiency with enhanced safety measures (Loei Rajabhat University, 2018; Acharry, 2019). Through SSC, the barriers posed by limited resources and large classroom sizes are mitigated, empowering educators to provide students with a more engaging and practical chemistry education.

The existing challenges in the realm of chemistry education in Thailand underscore the need for a fresh approach that can truly align with the intended educational objectives. In light of this, chemistry educators should embark on an exploration of diverse and impactful teaching methodologies that place student-centered learning at the forefront. Vital to this transformation is the provision of direct experiences and opportunities for self-directed learning and the active construction of knowledge, employing the scientific method and its associated processes. To raise the bar of chemistry education, the cultivation of innovative teaching strategies becomes paramount within the field.

Given the aforementioned challenges, a pedagogical breakthrough in chemistry education manifests in the context-based small scale chemistry STEM (CSSC-STEM) model. This innovative framework advocates for the seamless integration of SSC with STEM education, harnessing real-world scenarios and localized contextual challenges as effective conduits for learning and understanding. Through this model, the barriers to engaging chemistry education are dismantled, paving the way for a more dynamic and meaningful learning journey.

The challenges associated with teaching and learning chemistry in Thailand indicate that past efforts have not successfully met the established goals. To address this, chemistry educators should explore a range of effective teaching methods that prioritize student-centered learning. It is imperative to offer students more direct experiences and occasions for autonomous learning and knowledge construction, employing the scientific method and processes. To elevate the standard of chemistry education, the development of innovative teaching methods in the field is essential. Given the previously highlighted challenges, a pedagogical innovation for chemistry education emerges in the form of the context-based small scale chemistry STEM (CSSC-STEM) model. This model advocates the integration of SSC with STEM education, utilizing real-life situations and local contextual problems to facilitate effective learning.

2. Literature review

2.1. STEM education

The National Education Act of 1999, Section 24(1), emphasizes that educators must align the content and activities with the interests and aptitudes of students, taking into consideration individual differences. It underscores the need for teachers to cultivate skills, thinking processes, management strategies, problem-solving abilities, and the application of knowledge through real-life situations. Additionally, it encourages a focus on hands-on learning, practical exercises, critical thinking, action-based learning, cultivating a love for reading, and fostering continuous curiosity (National Education Act, 1999: 8).

Further elaborated in the revised version (Edition 2) of the National Education Act of 2002, Section 22 states that education must be founded on the principle that every student possesses the capability to learn and develop themselves to the best of their potential (National Education Act, 2002). IPST (2017) recognizes the significance of science education and acknowledges its paramount aim to achieve the most substantial impact on learners. Accordingly, it has established measurement criteria and core learning content for the science curriculum, following the 2008 Basic Education Core Curriculum (B.E. 2551). This curriculum outlines the objectives of science education, emphasizing a focus on self-discovery for learners, aiming to derive knowledge primarily through processes such as observation, investigation, experimentation, followed by the systematic organization of acquired results into principles, concepts, and foundational knowledge. The goal of science education is to integrate knowledge and understanding into beneficial applications for society and daily life, while also nurturing critical thinking, imaginative capabilities, problem-solving skills, communication skills, and decision-making abilities (Ministry of Education, 2017: 3).

Numerous pedagogical approaches align with the student-centered approach, and all of them are crafted to cultivate the growth of 21st-century skills. STEM education stands out as one of these approaches. STEM education is a learning approach that arises from the integration of knowledge in the fields of science, technology, engineering, and mathematics, employing engineering processes. It emphasizes having learners apply theoretical knowledge to solve real-life problems and develop novel processes or products for the benefit of society. This method encourages learners to recognize the significance of science and technology knowledge, which forms essential foundational skills for daily life, occupational pursuits, and national development (Ministry of Education, 2013: 16; Saneewong, 2013: 30; Siriphatrachai, 2013: 49; Thongchai, 2013; Chanprasert, 2014; Somahito, 2014).

Implementing education based on the STEM approach involves various concepts and characteristics. It integrates different disciplines, including science (S), technology (T), engineering (E), and mathematics (M), by synergizing the strengths of each field's nature and teaching methodologies. This aids students in creating connections between the content of these four subjects and everyday life and professional practices. It places emphasis on skill development for the 21st-century, challenges students' thinking, provides opportunities for students to express their opinions, and prioritizes the learner. The teaching format encourages thinking and planning, employing a step-by-step process. This teaching methodology promotes comprehensive development in various aspects among students, aligning with the direction of developing quality individuals in the 21st-century (Siriphatrachai, 2013; Thongchai, 2013).

Many educators have proposed steps in teaching by STEM education (Lou *et al.*, 2011; National Research Council, 2012; Schachter, 2012; National Center for STEM Education of Institute for the Promotion of Teaching Science and Technology, 2015; Thongchai, 2013). The authors analyzed the common teaching steps of STEM education, and the outcome has been summarized in **Table 1**.

Table 1. Common teaching steps of STEM education.

Lou *et al.* (2010)	Schachter (2012)	National Institute for STEM Education (2014)	National Research Council (2012)	Apisit Thongchai (2013)	Common teaching stepts of STEM education
Identify a problem	Pose a question	Identify a problem	Identify a problem	Identify a problem or need	Identification of the problem in local context
Explain the problem	Imagine	Gather data and relevant ideas related to the problem	Explore correct idea	Gather information	Gather data and relevant ideas
Plan	Plan	Plan to solve the problem	Plan and develop	Desigan and choose method	Problem-solving Design
Follow the plan	Construct	Desigan a method to solve the problem		Act	Practice
Evaluate	Revise	Test, evaluate and refine problem-solving methods to improve results	Test and evaluate	Test, revise, and evaluate	Test, improvement and evaluation
		Present problem-solving methods and the results	Present problem-solving results		Presentation

2.2. Small scale chemistry

Small scale chemistry (SSC) has been developed from Microscale experiments, which originated in 1983 and were first introduced at the college level. It was initially applied to organic chemistry experiments for students. Subsequently, its utilization expanded across college and university levels in more than 400 institutions in the United States. SSC is, therefore, a modern instructional method for conducting chemical experiments, focusing on safety, cost-efficiency, convenience, and speed. This approach involves utilizing smaller quantities of chemicals and repurposing containers, which are reusable materials that hold the chemicals during experimentation. These containers are portable, and many of the materials used for chemical reactions are ones that students encounter in their daily lives. By employing minimal amounts of chemicals, the chances of students and teachers coming into contact with hazardous substances are significantly reduced. In the event of a spill or leakage, the impact is relatively mild compared to experiments that involve larger quantities of chemicals. This allows for quicker mitigation of any situations that may arise. Kellly and Finlayson (2022) mentioned that SSC involves minimizing the quantity of chemicals used in experiments while still yielding satisfactory results. This practice aims to maintain environmental sustainability and prevent pollution by utilizing minimal quantities of chemicals without compromising quality, accuracy, and precision. This approach can reduce chemical usage by up to 80-90%. As a result, SSC offer a higher level of safety compared to traditional chemical experiments and require less time for experimentation. This method has been endorsed by various sources (Rajabhat Loei University, 2021) as a safer and more time-efficient alternative to current chemical experimentation practices. Furthermore, it contributes to a reduction in the volume of hazardous chemical waste (Wood, 1990). The instructional technique concerning SSC Presently, SSC is increasingly incorporated into high school-level experimentations due to the advantages it offers. SSC is recognized for its time efficiency, safety, and reduced costs since it requires minimal quantities of chemicals. (Tontayanon, 2011; Singhet *et al.*, 1999).

The application of SSC techniques can be effectively integrated into teaching chemistry at both the secondary and tertiary education levels. This approach offers various advantages, including reduced experimentation time and ease of equipment cleanup. Consequently, educators can incorporate experiments more frequently, allowing more time for collaborative classroom discussions of experimental outcomes. Safety during experimentation is enhanced, while costs associated with chemical procurement and disposal are minimized. Notably, every student in the classroom has the opportunity to conduct experiments individually, eliminating the need for group-based experiments. This method is adaptable to students of all ages and aptitudes, resulting in significant learning outcomes comparable to traditional laboratory experiments. Therefore, SSC has the potential to yield numerous benefits, including the development of scientific process skills and analytical thinking in students, providing them with direct experiential learning.

3. Methodology

This study employed a Research and Development (R&D) methodology in three cycles, namely R1D1, R2D2, and R3D3. R1D1 was conducted during the academic year 2019, from October 2019 to March 2020. R2D2 took place in the first semester of the academic year 2020, from July to August 2020. Finally, R3D3 was carried out in the first semester of the academic year 2021, from July to August 2021. The details of R1D1, R2D2, and R3D3 can be illustrated as follows.

3.1. R1D1

3.1.1. R1

The first R&D cycle has been occurred in the 2nd semester of 2019 academic year at Srisawatwittayakarnchangwatnan School, Nan Province, Thailand. This cycle aimed to explore teachers' and students' perspectives on current state, problems and needs of teaching and learning about chemistry.

3.1.2. Population and sample

3.1.2.1. Teachers

The population consisted of 60 chemistry teachers within the Nan Educational Area Office's jurisdiction, located in Nan Province, Thailand. Data were gathered from the entire population.

3.1.2.2. Students

The population comprised 204 Grade 11 students who were enrolled in the 2nd semester of the 2019 academic year at Srisawatwittayakarnchangwatnan School in Nan Province, Thailand. The sample consisted of 136 Grade 11 students who had previously studied chemistry using the SSC approach on chemical reaction rates during the 1st semester of the 2019 academic year.

3.1.3. Data collection

The questionnaires investigating the viewpoints of both teachers and students regarding the current state, problems and needs of teaching and learning chemistry comprised three main sections: a) background; b) perspectives on the current state, problems and needs of teaching and learning chemistry; and c) Suggestion for improving teaching and learning chemistry. The perspectives on the current state of teaching and learning chemistry were consisted of 8 items; the perspectives on the problems of teaching and learning chemistry were consisted of 7 items; and the perspectives on the needs of teaching and learning chemistry were consisted of 8 items.

The questionnaires exploring the teachers' and students' perspectives on the current state, problems and needs of teaching and learning chemistry utilized a five-point survey scale, encompassing options from strongly disagree (1), disagree (2), neutral (3), agree (4) to strongly agree (5).

The teachers' and students' perspective on current state, problems and needs of teaching and learning about chemistry questionnaires was validated the congruence between the questions and the objectives (Index of Item-Objective Congruence: IOC) by a panel of five experts. The IOC of questionnaire items related to current state, problems and needs of teaching and learning about chemistry was 1.00 that were acceptable. The researcher has revised and improved the questionnaire according to the recommendations of experts. Subsequently, the researchers tried out the current state, problems and needs of teaching chemistry questionnaire (Teacher Version) with 60 teachers. Then, the analysis was conducted to find reliability by calculating Cronbach's alpha coefficient, which equals 0.83, that was acceptable. In addition, the researchers tried out the current state, problems and needs of learning chemistry questionnaire (Student Version) with 136 individuals, who had previously learned through STEM education or had experience with SSC. The analysis was conducted to find reliability by calculating Cronbach's alpha coefficient, which equals 0.81, that was acceptable.

3.1.4. Data analysis

The data derived from the questionnaires exploring the teachers' and students' perspectives on the current state, problems and needs of teaching and learning chemistry were analyzed for frequency, percentage, mean and standard deviation (SD). Then, the authors interpreted the mean range of each item and the overall in three dimensions, i.e., current state, problems and needs.

3.1.5. D1

The authors developed the Context-based Small Scale Chemistry STEM (CSSC-STEM) model and asked five experts to validate its Suitability, Correspondence, Feasibility, and Potential Benefits. The results affirmed that the CSSC-STEM model was qualified. Therefore, the CSSC-STEM model was implemented with the experiment group and examined its effects on their learning achievement and learning and innovation skills in the R2D2 loop.

3.2. R2D2

3.2.1. R2

In this R&D loop, the independent variable was the utilization of the Context-based Small Scale Chemistry STEM (CSSC-STEM) model. The dependent variables were students' learning achievements as well as learning and innovation skills. The content used in this study is the chemical reaction rate in the chemistry subject at the Grade 11 level, according to the Basic Education Core Curriculum B.E. 2551 (Revised Version, B.E. 2560). The instruction time for teaching this content was a total of 24 hours.

3.2.2. Population and sample

The population consisted of 224 Grade 11 students who were enrolled in the second semester of the 2019 academic year at Srisawatwittayakarnchangwatnan School, Nan Province, Thailand. A sample of 84 Grade 11 students was randomly selected from two classrooms. The sample was chosen through Cluster Random Sampling, with classrooms as the sampling units. One classroom was randomly designated as the experimental group, while the other was randomly assigned as the control group. The experimental group, which engaged in learning through the Context-based small-scale chemistry STEM (CSSC-STEM) model, consisted of 43 students from Classroom 5/7. On the other hand, the control group, who followed the conventional approach using chemistry textbooks and manuals, was comprised of 41 students from Classroom 5/5.

3.2.3. Data collection

The authors created two major research instruments called the Learning Achievement Test and the Learning and Innovation Skills Test.

The Learning Achievement Test was a multiple-choice exam consisting of four options (a, b. c and d). It comprised the questions related to the rate of chemical reactions, totaling 40 questions. The exam duration is 45 minutes. It is administered both before and after each CSSC-STEM lesson. The exams for pre-lesson and post-lesson were the same set but with questions and options shuffled. The IOC of the learning achievement test ranged from 0.60 to 1.00 that was in acceptable level. In addition, the learning achievement test was piloted with 40 students, who had completed Chemistry. The item difficulty (p) and item discrimination (r) were calculated for each item. Only items with difficulty values between 0.20 and 0.80 and discrimination values above 0.20 were selected. Pre- and post-test exams consisted of 10 items each. In total, the Learning Achievement Test were consisted of 40 items. In addition, the researchers utilized

Lovett's method to establish the reliability of the test and found that the reliability of learning achievement test was 0.87, that was acceptable.

The learning and innovation skills test consisted of three major parts: a) critical thinking skills; b) creative thinking for innovation skills; and c) communication and collaboration skills. The details of each part were as follows.

The critical thinking skills (Learning Skills) test was in the form of an essay exam. Students were required to read the provided situations and answer questions based on them. The assessment of critical thinking skills is conducted both before and after each lesson, and the situations provided for each assessment were different. There were two situations, each with four essay questions, 16 questions in total. Each question is worth 4 points, with a maximum score of 32 points. The test duration is 30 minutes.

The creative thinking for innovation (Learning Skills) test was in the form of an essay exam. Students were required to read the provided situations and answer questions based on them. The assessment of creative thinking skills for innovation was conducted both before and after the lesson, and the situations provided for assessment were different. There were two situations, each with three essay questions, six questions in total. Each question is worth four points, with a maximum score of 24 points. The test duration is 30 minutes.

The communication and teamwork skills (Innovation Skills) test focused on assessing student behaviors in communication and teamwork practices. It included questions related to communication skills in speaking, writing, and comprehension (5 questions), and behaviors of collaboration with others emphasizing teamwork (6 questions). These are measured on a 5-level Likert scale ranged from consistently demonstrating the behavior, often demonstrating the behavior, sometimes demonstrating the behavior, rarely demonstrating the behavior, and never demonstrating the behavior (11 items in total).

The IOC of critical thinking skills test was 0.80 that was in acceptable level. The IOC of creative thinking for innovation skills test was 0.80 that was in acceptable level. Also, the IOC of communication and teamwork skills test ranged from 0.60 to 0.80 that was in acceptable level.

3.2.4. Data analysis

The researcher analyzed quantitative data using both descriptive statistics, including frequency, percentage, mean, standard deviation, and inferential statistics as independent t-test and dependent t-test.

3.2.5. D2

In the Development phase, the researchers employed the data from research 2 (R2) to improve the CSSC-STEM model and its associated lesson plans for improving Grade 11 students' academic achievement and their learning and innovation skills in the context of chemical reaction rates.

3.3. R3D3

The R3D3 cycle aimed to assess the consistency of the CSSC-STEM model in fostering students' academic achievements and enhancing their learning and innovation skills. As a result, the procedure of R3D3 replicated that of R2D2, albeit taking place in the subsequent academic year.

3.3.1. Population and sample

The study population included 216 Grade 11 students enrolled in the second semester of the 2021 academic year at Srisawatwittayakarnchangwatnan School, Nan Province, Thailand. A sample of 76 Grade 11 students was randomly selected from two classrooms through Cluster Random Sampling, using classrooms as the sampling units One classroom was randomly chosen to serve as the experimental group, while the other was randomly assigned as the control group. The experimental group comprised 40 students from Classroom 5/7, and the control group consisted of 36 students from Classroom 5/5.

3.3.2. Data collection and analysis

The R3D3 cycle aimed to assess the consistency of the CSSC-STEM model in fostering students' academic achievements and enhancing their learning and innovation skills. As a result, the procedure of data collection and analysis in R3D3 loop was replicated that of R2D2.

4. Results

4.1. Current state, problems and needs of teaching and learning chemistry

The teachers expressed their opinions about the current state, problems and needs of teaching and learning chemistry as Table 2.

Table 2. Teachers' opinions about the current state, problems and needs of teaching and learning chemistry.

Aspects	Mean	SD	Interpretation
Current state	3.98	0.86	High
Problems	3.95	0.88	High
Needs	4.43	0.59	High

The chemistry teachers expressed their opinions about the current state, problems and needs of teaching chemistry in the high (mean = 4.17, SD = 0.74), high (mean = 4.20, SD = 0.97) and very high (mean = 4.55, SD = 0.50) levels, respectively.

The students expressed their opinions about the current state, problems and needs of teaching and learning chemistry as Table 3.

Table 3. Students' opinions about the current state, problems and needs of teaching and learning chemistry.

Aspects	Mean	SD	Interpretation
Current state	3.51	0.92	High
Problems	3.63	0.94	High
Needs	3.77	0.90	High

The responding students reflected the high level of current state (mean = 3.67, SD = 0.91), problems (mean = 3.76, SD = 0.92) and needs (mean = 3.81, SD = 0.96) concerning learning chemistry.

4.2. Development of context-based small-scale chemistry STEM (CSSC-STEM) model

In this study, the researchers blended SSC and STEM education, incorporating various real-life situations within the students' local contexts through context-based learning (CBL). The researchers chose to incorporate chemistry content by aligning with chemicals, materials, and scenarios that closely relate to students' lives, such as cooking, baking, rusting, burning and so on. The laboratory activities created were partly restructured and partly refined from existing ones. The researcher chose to employ chemicals commonly found in daily life and utilized locally available materials and equipment. For instance, transparent drinking straws that had been used were repurposed as experimental tubes, and eggshells and seashells were used as substitutes for calcium carbonate. These materials were safe, cost-effective, and eco-friendly. They were adapted to suit the local context of the students. The teaching steps of CSSC-STEM model can be shown as Table 4.

Table 4. Summarized teaching steps of CSSC-STEM model.

Concept and Principle of STEM Education	STEM education is an approach that integrates knowledge from science, technology, engineering, and mathematics through engineering processes. It emphasizes having students apply theoretical knowledge to solve real-life problems and develop new processes or beneficial products. This leads to students recognizing the significance of scientific and technological knowledge, which are fundamental skills for sustainable living, professional careers, and national development.
Concept and Principle of SSC	SSC is a new teaching method for conducting chemical experiments that are highly safe, cost-effective, convenient, and fast. They make chemical experiments easily accessible, using minimal chemicals while maintaining quality, accuracy, and precision. The containers used to hold chemicals in these experiments are reusable materials that can be used again. They are easily transportable. Various materials used in conducting chemical reactions in these experiments are common items that students encounter in their daily lives.
Concept and Principle of context-based learning	CBL refers to the integration of various situations or events closely related to the students' real-life contexts. These connections aim to bridge classroom learning with real-life situations and challenges, thereby enhancing the students' abilities. By learning from diverse contexts that are interconnected with the chemistry knowledge to be imparted, students are encouraged to fully utilize their knowledge and thinking abilities. Moreover, they can effectively transfer these understandings to other situations or events.
Summarized teaching steps of CSSC-STEM Model	Identification of the problem in local context Gather data and relevant ideas Problem solving design Practice Test, improvement and evaluation Presentation

The following are descriptions of each teaching step of CSSC-STEM model.

Teaching step 1: Identification of the problem in local context

The teacher begins by evaluating students' existing knowledge through appropriate methods, ensuring they possess a solid foundation for upcoming material. Subsequently, the teacher introduces practical real-world challenges aligned with students' environment, employing captivating and fitting media or technology tailored to each unique problem context. Next, students individually pinpoint issues within situations that intrigue them, devising potential solutions before assembling into groups according to their preferences. In these groups, they collaboratively compile and evaluate problems, ultimately selecting a shared area of interest to tackle together.

Teaching step 2: Gather data and relevant ideas

Each student group collaboratively compiles relevant information and scientific ideas that pertain to problem-solving methodologies in science, mathematics, and technology, which are applicable to the selected issue. Concurrently, they establish the problem's objectives and scope, while also scrutinizing the conditions and limitations that come with solving it. Diverse educational materials, such as textbooks, online resources, and informational sheets, can be utilized for data collection. Additionally, the teacher employs concise chemical experiments to enhance students' comprehension, thereby contributing to the development of forthcoming problem-solving strategies.

Teaching step 3: Problem-solving design

In each student group, they collaboratively devise potential problem-solving methodologies by applying the information collected from the preceding steps. This involves considering locally available materials, situational constraints, and conditions, while also evaluating the feasibility of each approach. Eventually, the best problem-solving approach is selected for designing the project. Subsequently, the groups jointly establish a sequence of steps for crafting the project, followed by individual student presentations to the class. This allows the teacher and peers to inquire, provide suggestions, and offer additional problem-solving insights. Students then take this feedback to refine and enhance their problem-solving method design.

Teaching step 4: Practice

Students in each group proceed to create projects or develop methods according to the problem-solving steps they have designed. The teacher supervises the group work and provides guidance if students encounter challenges while crafting their projects or refining methods for problem-solving.

Teaching step 5: Test, improvement, and evaluation

Students conduct testing on their projects or problem-solving methods and subsequently evaluate the outcomes to pinpoint opportunities for enhancement and growth, ensuring the efficacy of their problem-solving endeavors. The iterative process of testing and refining projects or problem-solving methods can be executed multiple times within the allocated timeframe. The teacher underscores the significance of carefully recording testing outcomes and the specifics of each modification undertaken, facilitating the utilization of this data for forthcoming presentations.

Teaching step 6: Presentation

Each group of students presents their projects or problem-solving methods along with the relevant principles or design concepts. After the presentation, classmates collectively ask questions, discuss, and provide suggestions to enhance the projects or problem-solving methods. The teacher encourages an interactive and creative presentation atmosphere.

The researchers presented the CSSC-STEM model to a panel of five experts to evaluate its quality in four aspects: suitability, correspondence, feasibility, and potential benefits. The results of expert evaluation of the CSSC-STEM model are shown in Table 5.

Table 5. Assessment of the CSSC-STEM Model's quality by a panel of experts.

Item	Statement	Mean	SD	Interpretation
	Suitability			
1.	The CSSC-STEM model is aligned with the utilized concepts/theories in its development.	4.40	0.49	High
2.	The CSSC-STEM model is suitable for improving learning outcomes.	4.40	0.49	High
3.	The CSSC-STEM model is suitable in developing students' learning and innovation skills.	4.20	0.75	High
4.	The component of CSSC-STEM mode is suitable.	4.40	0.49	High
5.	The CSSC-STEM model is suitable for further development and dissemination on a broader scale.	4.60	0.49	Very high
6.	The teaching steps of CSSC-STEM model are undertaken through appropriate analysis and synthesis.	4.60	0.49	Very high
	Overall average in suitability	**4.43**	**0.56**	**High**
	Correspondence			
7.	The CSSC-STEM model is corresponded with the current state of instructional management issues.	5.00	0.00	Very high
8.	The CSSC-STEM model is corresponded with the needs of current teaching management.	4.40	0.49	High
9.	The CSSC-STEM model is corresponded to the development of learning quality according to the curriculum.	4.40	0.49	High
10.	All components of the CSSC-STEM model have internal correspondence.	4.60	0.49	Very high
11.	The synthesized teaching steps of CSSC-STEM model are aligned with the CSSC-STEM conceptual framework.	4.20	0.40	High
	Overall average in correspondence	**4.52**	**0.50**	**Very high**
	Feasibility			
12.	The CSSC-STEM model shows its creativity.	5.00	0.00	Very high
13.	The CSSC-STEM model is possible for application.	4.40	0.49	High
14.	The CSSC-STEM model is possible in developing students' learning achievement.	4.20	0.40	High
15.	The CSSC-STEM model is possible in developing learning and innovation skills.	5.00	0.00	Very high
16.	The CSSC-STEM model has its potential for application in other educational institutions.	4.20	0.75	High
	Overall average in feasibility	**4.56**	**0.57**	**Very high**
	Potential benefits			
17.	The CSSC-STEM model is beneficial for improving the quality of instructional management.	4.20	0.75	High
18.	The CSSC-STEM model is beneficial for developing students' learning achievement.	4.40	0.49	High
19.	The CSSC-STEM model is beneficial for developing learning and innovation skills.	4.60	0.49	Very high
20.	The CSSC-STEM model is beneficial for other teachers in the same subject.	4.60	0.49	Very high
21.	The CSSC-STEM model is beneficial for other teachers in the different subjects.	4.40	0.49	High
	Overall average in potential benefits	**4.44**	**0.57**	**High**

The experts evaluated the quality of CSSC-STEM model regarding its suitability, correspondence, feasibility, and potential benefits in High (mean = 4.43, SD = 0.56), Very high (mean = 4.52, SD = 0.50), Very high (mean = 4.56, SD = 0.57) and high (mean = 4.44, SD = 0.57) levels, respectively.

The researchers utilized the CSSC-STEM model to create four instructional plans, totaling 24 teaching hours, i.e., meaning of the rate of chemical reaction (6 h), concepts and energy involved in chemical reactions (4 h), factors affecting the rate of chemical reactions (6 h), and fermented pork sausage: like and sure (8 h).

In translating the CSSC-STEM model into practice, the researchers would like to present an example of lesson plan on the factors affecting the rate of chemical reactions as follows.

Teaching step 1: Identification of the problem in local context

The teacher presents video clips relevant to student contexts, illustrating the factors that influence the rate of chemical reactions.

From Video Clip 1, two individuals are washing dishes. Person 1 takes dishwashing liquid from a bottle using a teaspoon and adds it to a foam of water. They use it to remove grease from a plastic dish. Person 2 also takes dishwashing liquid from a bottle using a teaspoon and mixes it with water. They pour the mixture onto the foam to clean the greasy residue from the plastic dish. Students predict the outcome of the cleaning process, considering the differences in how person 1 and person 2 washed the dish, and explain the reasons behind it.

In Video Clip 2, there are two bundles of "Cha-om" (in Thai) or Chinese chives (garlic chives). One bundle was placed inside a refrigerator, while another placed outside the refrigerator. Students are asked to predict the outcome after leaving them for one day and explain the reasons behind it.

From Video Clip 3, salt crystals and finely ground salt are placed in two plastic glasses. Students are asked to predict the outcome of the experiment and explain the reasons behind it.

Students should be able to conclude that factors affecting the rate of chemical reactions include increasing concentration, increasing surface area, and raising the temperature. These are important factors that contribute to the faster occurrence of chemical reactions. However, sometimes following these methods can lead to time and cost inefficiencies. For instance, in reactions that require acids as starting materials in a production process, increasing the reaction rate by enhancing the acid concentration would result in higher costs. Additionally, dealing with the excess acid left after the reaction would require neutralization before disposal, leading to increased expenses. Similarly, if the reaction rate is increased by raising the temperature, it could lead to increased fuel consumption, making it impractical. Therefore, enhancing the concentration of starting materials or raising the temperature might not always be suitable for promoting rapid reaction rates.

Teaching step 2: Gather data and relevant ideas

The teacher sets the context for students to identify problems and define the requirements for problem-solving.

Student A will prepare a meal which is pineapple curry with boiled meat and eggs. Before starting, she prepares the ingredients in two separate bowls for convenience in cooking. In a small bowl, she puts pineapple juice, and in a larger bowl, she places chopped pineapple and sliced meat, with some parts of the meat mixed with the pineapple. While waiting for the cooking time, she peels the boiled eggs to prepare for consumption. By chance, the eggshell pieces fall into the pineapple juice in the bowl prepared to be used in the curry. She notices that gas bubbles start to form rapidly, and within a minute, the smaller eggshell pieces disappear. When she eats the pineapple curry, she notices that some meat pieces are tender while others are chewy, even though they come from the same meat. Curious about these two events, the students wonder why the smaller eggshell pieces disappeared in the pineapple juice in a shorter time compared to the larger pieces, and why some meat pieces are tender while others are chewy. She speculates that there might be something causing the eggshell to react differently in the pineapple juice and that mixing pineapple with the meat might influence the tenderness. To address these questions, the students plan to conduct experiments using household materials to investigate both scenarios.

The teacher instructs each student group to practice identifying problems and conditions on Activity Sheet related to finding factors affecting the rate of chemical reactions. The following is one example.

Identify the problem: How can the eggshell undergo a reaction in orange juice, resulting in varying rates of reaction, and why do certain pieces of the egg have different levels of firmness and stickiness?

Factors or Conditions: Conduct an experiment using household materials to address both suspected scenarios. There must be certain elements that cause the eggshell to react differently in orange juice, resulting in varying rates of reaction. Additionally, examine whether the presence of pineapple mixed with the egg has an impact on the texture and stickiness of the eggshell or if other factors influence the texture of the eggshell.

Each student group collaboratively gathers information and scientific ideas related to problem-solving approaches in chemistry, mathematical principles, and relevant technologies. These are pertinent to the selected problem-solving strategies derived from the contextual factors that influence chemical reactions. This enables students to comprehend the issues they have chosen and determine the objectives of problem-solving, problem scope, and analyze conditions or constraints involved. Each group is tasked with researching information from various sources such as the internet, textbooks, library resources, and knowledge sheets. They should outline the sequence of study for each activity and knowledge sheet to extract relevant data while indicating the sequence for effective learning.

The teacher distributes the experiment sheet: Calcium carbonate ($CaCO_3$) and acetic acid (CH_3COOH) affecting the chemical reaction. The purpose of this activity is to guide students in planning the experiment and ensuring they have all the necessary apparatuses ready.

The students are directed to follow the steps outlined in the experiment sheet and conduct the experiment regarding the factors influencing the chemical reaction between calcium carbonate ($CaCO_3$) and acetic acid (CH_3COOH). After completing the experiment, students are required to record their findings focusing on the factors affecting the chemical reaction between calcium carbonate ($CaCO_3$) and acetic acid (CH_3COOH). Additionally, students should establish the experiment's objectives, independent variables, dependent variables, controlled variables, and formulate hypotheses before proceeding with the experiment.

Students in each group should summarize the experimental results as follows.

Calcium carbonate ($CaCO_3$) and acetic acid (CH_3COOH) affecting the chemical reaction rate of eggshell with orange juice, resulting in varied time of gas bubble formation in Tubes 1-4:

- **Tube 1. Initial Surface Area of Reactants:** In this tube, the calcium carbonate ($CaCO_3$) and acetic acid (CH_3COOH) reaction was observed to produce gas bubbles within a certain time frame;
- **Tube 2. Comparative Control Tube:** This tube served as a control to compare the results of the other tubes. The reaction between calcium carbonate ($CaCO_3$) and acetic acid (CH_3COOH) was allowed to occur naturally;
- **Tube 3. Concentration of Reactants:** In this tube, a different concentration of reactants (calcium carbonate and acetic acid) was used to determine its effect on the rate of gas bubble formation;
- **Tube 4. Temperature:** This tube investigated the impact of temperature on the reaction rate by experimenting with a different temperature from the other tubes.

The results of this experiment show that various factors, including the initial surface area of reactants, concentration of reactants, and temperature, play a significant role in influencing the rate of chemical reactions. The differences observed in the time taken for gas bubble formation suggest that manipulating these factors can either accelerate or decelerate the reaction process. Furthermore, the eggshell and orange juice experiment also demonstrated how the reaction rate can be affected by the nature of the materials involved in the reaction.

The teacher distributed the experiment sheet titled "Effects of adding potassium iodide (KI) on the decomposition rate of hydrogen peroxide (H_2O_2)". This chemistry experiment aims to engage student groups in a concise chemical investigation. Collaboratively, students are tasked with gathering scientific concepts from the realm of chemistry, mathematical principles, and relevant technology. The chosen problem-solving approach stems from a specific scenario. The students then proceed to devise an experimental plan and ensure that all necessary apparatus is prepared. Upon completion of the experiment following the steps outlined in Activity Sheet, students are required to record their experimental results on the same sheet.

Students in each group should conclude that when adding KI solution to hydrogen peroxide (H_2O_2), the decomposition rate of H_2O_2 increases. The KI solution returns to its original state after the reaction concludes. Further explanation by the teacher: The catalyst participates in the reaction, but once the reaction is complete, the catalyst returns to its original state. This can be observed from the experiment, where the decomposition of hydrogen peroxide is accelerated upon adding potassium iodide. The chemical equations for the reactions are as follows (**Eq. 1** and **2**):

$$H_2O_2\,(aq) + I^-\,(aq) \rightarrow H_2O\,(l) + OI^-\,(aq) \quad (1)$$

$$OI^-\,(aq) + H_2O_2\,(aq) \rightarrow I^-\,(aq) + H_2O_2\,(l) + O_2\,(aq) \quad (2)$$

The acceleration of the reaction will lower the activation energy of the reaction, but the overall energy change of the reaction remains unchanged. The delayed reaction will also lower the activation energy of the reaction, but, like the acceleration, the overall energy change of the reaction remains unchanged.

Teaching step 3: Problem-solving design

The teacher instructs the students to collaborate in designing an experiment to create a model for testing the effects of slow reaction rates. Each group is provided with one sheet of graph paper and a simplified chemistry experiment kit. The students are tasked with collectively designing a problem-solving method by applying the information gathered from the previous steps. In this design process, each student group should consider using locally available materials and equipment. They are required to brainstorm and outline their plan on the paper before proceeding to draw a draft of the experimental setup.

Part 1: How can we induce different reaction rates of eggshell dissolution in vinegar?

Part 2: Testing the tenderness and stickiness of meat.

The teacher instructs each student group to present their design for the experiment to test the effects of reaction rate alteration. The teacher will randomly select each group to present using the PiliApp program.

Teaching step 4: Practice

Students proceed learning through the CSSC-STEM model based on their devised plans to address the aforementioned issues. Students record the step-by-step process of problem-solving as they work to test the impact of slow reaction rates. During the activity, the teacher will provide guidance and suggestions if students encounter difficulties.

Teaching step 5: Test, improvement, and evaluation

After designing and conducting the experiment, students may encounter challenges. What problems did the students encounter, and how did they suggest improving or modifying the experimental design? For groups that didn't achieve the expected outcomes or faced issues during the experiment, they can address the shortcomings and then proceed to experiment again. The students should have refined their models until they are successfully completed.

Teaching step 6: Presentation

Each student group present the relationship between S-T-E-M in their designed plan and process as well as the results of their plan to test the effect of the reaction rate of a chemical reaction. After the presentation, classmates should engage in questioning, discussion, and offering suggestions to enhance the project or problem-solving methods. An example of integrating knowledge from S-T-E-M (Science, Technology, Engineering, and Mathematics) is as follows:

Science: Scientific knowledge about factors affecting chemical reactions, including substance concentration, surface area, temperature, catalysts, and reaction accelerators;

Technology: Technologies help the experiment from planning to execution, obtaining results, and data collection e.g. using photography and video recording during the experiment;

Engineering: Using Engineering Design Process in designing problem-solving processes and products;

Mathematics: Measurement and calculation e.g. measuring time, counting gas bubbles, etc.

The teacher and students together summarize the knowledge gained from the lesson.

Chemical reactions in daily life can occur more rapidly or slowly when changing factors affecting the rate of reaction, as follows:

Nature of Reactants: Different types of reactants have varying reaction rates. Some substances react easily, while others react less readily;

Surface Area: Increasing the surface area of reactants leads to more collisions and faster reaction rates;

Concentration: Increasing the concentration of reactants speeds up the reaction, while decreasing it slows it down;

Temperature: Higher temperatures increase the kinetic energy of molecules, resulting in more frequent collisions and faster reactions;

Catalysts: Catalysts lower the activation energy, making the reaction proceed faster, and are not consumed in the process;

Inhibitors: Inhibitors raise the activation energy, leading to slower reactions.

Finally, the teacher encourages students to apply their constructed knowledge in providing examples of activities or everyday life events that are related to factors influencing the rate of chemical reactions.

4.3. Effects of CSSC-STEM model on students' learning achievement and learning and innovation skills: R2D2

The researchers evaluated the normal distribution of students' learning achievement scores through the Kolmogorov-Smirnov test. The analysis indicated that the data adhered to a normal distribution, enabling to proceed with inferential statistics. The comparison between the experiment and control groups' learning achievement was as follows.

Table 6. Independent t-test of learning achievement scores between the experiment and control groups.

Group	n	Mean	SD	t	p
Experiment group	43	28.79	4.378	7.599	0.000
Control group	41	21.63	4.247		

Table 6 showed that the Grade 11 students in the experimental group, who were taught using the CSSC-STEM model, demonstrated significantly higher learning achievement ($t = 7.599$, $p < 0.05$) in the rate of chemical reactions topic compared to the students in the control group.

Table 7. Dependent t-test of learning achievement scores of experiment group at the beginning and the end of CSSC-STEM model.

Group	n	Mean	SD	t	p
Pre-test	43	9.42	2.21	34.242	0.000
Post-test	43	28.79	4.38		

Table 7 showed that the Grade 11 students in the experimental group, who learned with the CSSC-STEM model, exhibited notably enhanced learning achievement in the post-test

($t = 34.242$, $p < 0.05$) for the topic of Rate of Chemical Reactions in comparison to their pre-test performance.

Table 8. Independent t-test of critical problem-solving skills between the experiment and control groups.

Group	n	Mean	SD	t	p
Experiment group	43	27.12	2.701	20.968	0.000
Control group	41	14.32	2.893		

Table 8 showed that the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, exhibited markedly improved critical problem-solving skills ($t = 20.968$, $p < 0.05$) in the rate of chemical reactions, surpassing the performance of students in the control group.

Table 9. Dependent t-test of critical thinking skills scores of experiment group at the beginning and the end of CSSC-STEM model.

Group	n	Mean	SD	t	p
Pre-test	43	5.40	1.256	50.459	0.000
Post-test	43	27.12	2.701		

From Table 9, the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, demonstrated significantly improved critical problem-solving skills in the post-test ($t = 50.459$, $p < 0.05$) related to rate of chemical reactions topic, compared to their performance in the pre-test.

Table 10. Independent t-test of creativity and innovation skills between the experiment and control groups.

Group	n	Mean	SD	t	p
Experiment group	43	19.60	2.461	23.168	0.000
Control group	41	8.71	1.778		

From Table 10, the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, exhibited markedly improved creativity and innovation skills ($t = 23.168$, $p < 0.05$) in rate of chemical reactions, surpassing the performance of students in the control group.

Table 11. Dependent t-test of creativity and innovation skills of experiment group at the beginning and the end of CSSC-STEM model.

Group	n	Mean	SD	t	p
Pre-test	43	5.67	1.304	36.843	0.000
Post-test	43	19.60	2.461		

From Table 11, the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, demonstrated significantly improved creativity and innovation skills in the post-test ($t = 36.843$, $p < 0.05$) related to rate of chemical reactions, compared to their performance in the pre-test.

Table 12. Development of students' communication and teamwork skills from instructional plans 1 to 4 of the CSSC-STEM model.

Lesson Plan	Total score	Mean	SD
1	55	46.09	2.068
2	55	49.26	2.094
3	55	50.65	1.660
4	55	51.91	1.211
Average	55	49.48	2.680

From Table 12, the experimental group, which learned through the CSSC-STEM model, exhibited a gradual enhancement in their communication and collaboration skills across instructional Plans 1 to 4.

4.4. Effects of CSSC-STEM model on students' learning achievement and learning and innovation skills: R3D3

The researchers evaluated the normal distribution of students' learning achievement scores through the Kolmogorov-Smirnov test. The analysis indicated that the data adhered to a normal distribution, enabling to proceed with inferential statistics. The comparison between the experiment and control groups' learning achievement was as follows.

Table 13. Independent t-test of learning achievement scores between the experiment and control groups.

Group	n	Mean	SD	t	p
Experiment group	40	33.50	4.358	13.342	0.000
Control group	36	22.50	2.408		

From Table 13, the Grade 11 students in the experimental group, who were taught using the CSSC-STEM model, demonstrated significantly higher learning achievement ($t = 13.342$, $p < 0.05$) in rate of chemical reactions compared to the students in the control group.

Table 14. Dependent t-test of learning achievement scores of experiment group at the beginning and the end of CSSC-STEM model.

Group	n	Mean	SD	t	p
Pre-test	40	9.55	2.087	36.658	0.000
Post-test	40	33.50	4.385		

From Table 14, the Grade 11 students in the experimental group, who were instructed using the CSSC-STEM model, exhibited notably enhanced learning achievement in the post-test ($t = 36.658$, $p < 0.05$) for rate of chemical reactions in comparison to their pre-test performance.

Table 15. Independent t-test of critical problem-solving skills between the experiment and control groups.

Group	n	Mean	SD	t	p
Experiment group	40	26.93	2.693	19.058	0.000
Control group	36	14.14	3.155		

From Table 15, the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, exhibited markedly improved critical problem-solving skills ($t = 19.058$, $p < 0.05$) in rate of chemical reactions, surpassing the performance of students in the control group.

Table 16. Dependent t-test of critical thinking skills scores of experiment group at the beginning and the end of CSSC-STEM model.

Group	n	Mean	SD	t	p
Pre-test	40	9.80	1.556	52.079	0.000
Post-test	40	26.93	2.693		

From Table 16, the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, demonstrated significantly improved critical problem-solving skills in the post-test ($t = 52.079$, $p < 0.05$) related to rate of chemical reactions, compared to their performance in the pre-test.

Table 17. Independent t-test of creativity and innovation skills between the experiment and control groups.

Group	n	Mean	SD	t	p
Experiment group	40	19.98	2.178	19.065	0.000
Control group	36	9.97	2.396		

Table 17 showed that the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, exhibited markedly improved creativity and innovation skills ($t = 19.065$, $p < 0.05$) in rate of chemical reactions, surpassing the performance of students in the control group.

Table 18. Dependent t-test of creativity and innovation skills of experiment group at the beginning and the end of CSSC-STEM model.

Group	n	Mean	SD	t	p
Pre-test	40	6.33	1.118	38.018	0.000
Post-test	40	19.98	2.178		

Table 18 showed the Grade 11 students in the experimental group, who received instruction through the CSSC-STEM model, demonstrated significantly improved creativity and innovation skills in the post-test ($t = 38.018$, $p < 0.05$) related to rate of chemical reactions, compared to their performance in the pre-test.

Table 19. Development of students' communication and teamwork skills from instructional plans 1 to 4 of the CSSC-STEM model.

Lesson Plan	Total score	Mean	SD
1	55	46.38	1.547
2	55	49.45	1.377
3	55	50.88	1.090
4	55	52.05	0.986
Average	55	49.46	1.230

Table 19 showed the experimental group, which learned through the CSSC-STEM model, exhibited a gradual enhancement in their communication and collaboration skills across instructional plans 1 to 4.

5. Discussion

The researchers found that the teachers expressed a high level of demand for the CSSC-STEM model, which combines SSC with STEM and context-based learning (CBL), because they perceive the potential benefits of SSC with STEM and CBL for developing learning and innovation skills. This is consistent with previous works (Thongchai, 2013; Siriphatraichai, 2013; Chaolumbua, 2013; Siriphatrachai, 2013; Loei Rajabhat University, 2018; Acharry, 2019). The integrative teaching approach in STEM, which incorporates four different disciplines, including Science (S), Technology (T), Engineering (E), and Mathematics (M). This amalgamation blends the strengths and teaching methods of each discipline to enable students to establish connections between the four subjects and their daily lives and future careers. This approach emphasizes the development of 21st-century skills, challenges students' thinking, and encourages them to voice their opinions, placing learner-centeredness at its core. The instructional design focuses on training students to think and plan using a step-by-step process. It aims to foster comprehensive growth across various domains and aligns with the development of quality skills for the 21st-century. Additionally, it corresponds with Chaiyasit Chanchaikaew's work in 2013 and Mahasarakham University in 2018, as well as the Chemical Society of Thailand and the Dow Group in 2019. They noted that SSC offer a safe, cost-effective, convenient, and efficient method for teaching chemistry. This method minimizes the use of chemicals and encourages the reuse of containers, allowing for easy transport. Utilizing various materials in chemistry experiments that students encounter in their daily lives with small quantities of chemicals reduces the risk of exposure, making it less dangerous. If an accident occurs, it can be quickly rectified compared to experiments that involve a large quantity of chemicals. SSC thus offer a safer alternative to current chemical experiments, requiring less time. Students' desire for integrative learning and SSC stems from the current context, problems, and educational needs, all of which are substantial. Their demand arises from a preference for engaging learning that goes beyond theoretical study. As Passakchai (2015) stated, relying solely on chemistry theories and lectures can lead to some students misunderstanding, causing genuine frustration and disinterest in chemistry.

The CSSC-STEM model is qualified in views of experts. It is appropriate for enhancing students' learning outcomes, learning and innovation skills, the researchers incorporated SSC into the process of gathering data related to a problem. They integrated situations inf SSC are close to the students in identifying contextualized problems within the local context, resulting in increased student engagement in learning. As noted by Siripatharachai (2013), SSC facilitates comprehensive development in various aspects, aligned with the 21st-century human development approach. This includes enhancing students' understanding of subject matter, higher-ordered thinking skills such as analysis and creative thinking, as well as fostering qualities such as effective teamwork, communication skills, leadership, and the ability to accept constructive criticism from others.

The CSSC-STEM model promotes self-directed learning among students through a diverse range of activities. These activities align with the guidelines for organizing science learning activities specified in the curriculum. Additionally, the approach involves studying and analyzing students to understand their potential and needs. It follows a systematic process for creating a well-structured learning plan, incorporating appropriate and accurate steps. This includes analyzing foundational data related to the current situation and challenges in teaching and learning chemistry at the Grade 11. The curriculum, theories, principles, ideas, documents, and research related to SSC, STEM and CBL are considered. A panel of expert also provide comments and suggestions to various aspects such as content, language use, activity design, and assessment methods.

The CSSC-STEM model significantly promotes students critical problem-solving skills, creativity and innovation skills and communication and collaboration skills.

In alignment with Chaolumbua (2015), STEM education can foster learners' skills such as critical thinking, systematic scientific learning, and the creation of new generations of innovators. It supports sustainable innovation and new processes, adapting to the rapidly changing economic landscape. These innovations are fundamentally rooted in knowledge from science, technology, engineering, and mathematics (STEM), particularly through STEM content learning. This occurs via engineering design processes (EDP), which help cultivate desired habits of mind and essential skills for the 21st-century. In accordance with the mentioned context, the EDP serves as an accelerator for integrating STEM content, aiding the development of essential skills for national progress.

In accordance with Acharry (2009), the utilization of SSC in learning activities involves the use of minimal quantities of chemicals and reuses containers for chemical experimentation, enhancing portability. Various materials employed in chemical reactions are common in everyday life, and students' personal involvement in conducting hands-on experiments fosters curiosity and enthusiasm for learning. This approach, SSC, enables students to develop scientific process skills and swiftly and clearly observe experimental outcomes. Simultaneously, teachers' instructional strategies, punctuated with periodic questioning, stimulate greater classroom participation. Students become more confident in expressing their doubts and findings, promoting an environment that supports the contextualized learning format of combining chemical experimentation with local contexts. This is congruent with the topic of chemical reaction rates, which the researchers developed, exhibiting significantly higher effectiveness compared to the standard criteria. After learned with SSC combined with STEM education, students had significantly higher learning achievement than students undergoing conventional instruction ($t = 7.599$, $p < .05$).

Aligned with the research findings (Khammamung, 2017; Wicheansang *et al*., 2018; Khonchaiyapham, 2017; Poonruang, 2016; Saengpromsri, 2015), this is due to the systematic evaluation of the tool's efficacy before its application within the sample group. The researchers recognized the significance of student-centered instructional activities, emphasizing the use of engaging teaching materials. These materials are derived from items close to students' daily lives, enhancing accelerated learning. Once students successfully design and implement their projects, they are able to consume their creations, such as pork jerky and marinated meat with pineapple. The designed learning activities also consider individual differences, and the experiences students engage in, resulting in interconnected knowledge acquisition. This interaction fosters students' critical thinking and deepens their understanding, consequently elevating the quality of their learning outcomes. Based on these reasons, it can be concluded that employing the CSSC-STEM model and its lesson plans significantly contributes to students' learning achievement development. It affirms that the CSSC-STEM learning activities play a vital role in advancing students' learning quality.

The CSSC-STEM model significantly promotes students learning and innovation skills. Siripithayachai (2013) suggests that teachers should employ a science teaching approach aligned with the constructivist concept, which can generate student interest, excitement, challenge, and confidence in learning. This leads to an increased inclination among students to study science at higher levels and achieve success in their studies. Pholchayachaya (2014) stated that organizing learning through inquiry-based activities is a method that helps students develop more creative thinking skills. Furthermore, creative thinking is a crucial skill for learning in the 21st-century. Chanprasert (2014) stated that contemporary teaching must be aligned with the rapidly changing 21st-century society. Learners need to develop various skills necessary for the 21st-century. Organizing learning in the 21st-century is guided by key principles, such as learner-centeredness, hands-on activities, and objectives aimed at enhancing students' learning capabilities, including advanced thinking skills. The researcher has designed activities in the CSSC-STEM model that correspond to various skills necessary in the 21st-century. As a result, students' learning and innovation skills are higher compared to those learning through conventional methods.

In R3D3, the CSSC-STEM model still constantly continues to produce positive impacts on Grade 11 students' learning achievement and learning and innovation skills. This phenomenon underscores the consistency and reliability of the newly developed model in this study i.e., the CSSC-STEM model.

6. Conclusions

The CSSC-STEM model developed in this study has been demonstrated as an innovative and effective teaching approach for enhancing Grade 11 students' academic performance and fostering their learning and innovation skills in the field of chemical reaction rates in chemistry. The research and development (R&D) methodology progressed from the development phase (R1D1) through the implementation phase (R2D2) and replication phase (R3D3) yield the completed version of CSSC-STEM model, which is ready to be implemented in other chemistry classroom settings. The challenge lies in determining whether the CSSC-STEM model is effective for teaching topics beyond chemical reactions, extending to other areas of chemistry or even other scientific subjects such as physics and biology. Furthermore, the examination of the impacts of the CSSC-STEM model on other dependent variables awaits further research conducted by other researchers.

Authors' contributions

Conceptualization: Ratanaphun Utmeemang; Khajornsak Buaraphan; **Data curation:** Ratanaphun Utmeemang; **Formal Analysis:** Ratanaphun Utmeemang; **Funding acquisition:** Ratanaphun Utmeemang; **Investigation:** Ratanaphun Utmeemang; **Methodology:** Ratanaphun Utmeemang; Khajornsak Buaraphan; **Project administration:** Ratanaphun Utmeemang; Khajornsak Buaraphan; **Resources:** Ratanaphun Utmeemang; **Software:** Khajornsak Buaraphan; **Supervision:** Khajornsak Buaraphan; **Validation:** Ratanaphun Utmeemang; Khajornsak Buaraphan; **Visualization:** Ratanaphun Utmeemang; Khajornsak Buaraphan; **Writing – original draft:** Ratanaphun Utmeemang; **Writing – review & editing:** Khajornsak Buaraphan.

Data availability statement

The data will be available upon request.

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