Research Article

Enhancing Science Communication Skills for Future Science Teachers: A Redesign of Inquiry-Based Learning

Pusanisa Suwansil[1] and Chaninan Pruekpramool[2*]

Received: 18 October 2024
Revised: 3 December 2024
Accepted: 16 December 2024

ABSTRACT

Science communication skills are crucial for science teachers but are often neglected in traditional inquiry-based learning. This study addresses this gap by revising the inquiry-based learning model to integrate communication strategies, aiming to promote the science communication skills of pre-service science teachers in Thailand. The study involved 25 third-year pre-service science teachers enrolled in a science program at a Rajabhat University in central Thailand. The learning model was developed using a research and development process. Research instruments included lesson plans, science communication skills tests, and a science learning achievement test. Data analysis was conducted using percentage, mean, standard deviation, relative gain score, and a t-test for dependent samples. The redesigned inquiry learning model featured five steps: engagement, exploration and inference, logical explanation, analytical elaboration, and evaluation. Results showed that after learning with this model, pre-service teachers achieved the highest mean scores in summarizing scientific concepts, followed by interpreting data with scientific evidence, and explaining scientific phenomena. Additionally, the relative gain scores of science communication skills increased significantly, moving from moderate to very high levels across seven phases. The posttest mean score for science learning achievement was also significantly higher than the pretest score ($t = -15.19$, $p < .001$). This innovative approach demonstrates the potential of combining inquiry-based learning with communication strategies to effectively enhance science communication skills and overall learning achievements of future science teachers.

Keywords: Science communication, Inquiry-based learning, Pre-service teachers, Learning model

[1] Faculty of Education, Phranakhon Si Ayutthaya Rajabhat University, Phranakhon Si Ayutthaya 13000, Thailand
[2] Science Education Center, Faculty of Science, Srinakharinwirot University, Bangkok 10110, Thailand
[*]Corresponding author, email: chaninan@g.swu.ac.th

Introduction

Science communication skills are essential in effectively transferring data, drawing scientific conclusions, interpreting empirical evidence, and explaining scientific phenomena [1-5]. These skills can be assessed through communication behavior evaluations using science communication skill assessment forms [2, 6-7]. They are vital for keeping the public informed about global situations, climate changes, scientific innovations, and technologies [2, 4, 8]. Additionally, they empower individuals to make informed decisions based on evidence and reason, such as disease prevention in healthcare [9], adapting to environmental changes, and making quality food choices [10, 11]. For scientific knowledge senders, particularly science teachers, these skills are indispensable [12]. Science teachers play a crucial role in developing students' understanding of scientific concepts [13]. A thorough grasp of scientific principles enables teachers to help students comprehend scientific content, develop a genuine understanding of science, explain natural phenomena, and present scientific data effectively [14].

In Thailand, Rajabhat Universities serve as educational institutions with the primary mission of producing and developing teachers across all disciplines, including science teachers. Their core responsibility is to prepare students to effectively perform teaching roles in various subjects at schools and to advance in their professional teaching careers. One of the expected learning outcomes of the science teacher education program is that graduates must be capable of conducting science instruction at the basic education level with professionalism. Additionally, they are expected to possess essential 21st-century skills, including communication skills specifically, the ability to use both verbal and written communication effectively and appropriately [15]. Reviewing relevant research studies and documents revealed that pre-service science teachers undergoing teacher development processes lacked sufficient science communication skills to effectively transfer scientific knowledge to students [16]. To explore this issue further, the researcher interviewed university supervisors and school advisors at a Rajabhat University in central Thailand. The findings indicated that while pre-service science teachers generally possessed adequate scientific knowledge for teaching, they struggled with providing oral and written explanations of complex issues at appropriate levels for their students. They also faced challenges in connecting scientific concepts to draw conclusions, reflecting difficulties in summarizing scientific concepts, which is a key component of science communication skills. Additionally, they struggled to reference sufficient evidence and to select and use empirical scientific evidence to comprehensively explain data. For example, pre-service science teachers often explained concepts without scientific justification and provided unclear examples of real-world situations. This corresponds to issues in two other critical components of science communication skills: interpreting data using scientific evidence and explaining scientific phenomena [17].

Moreover, based on the researcher's experience in teaching the course "Earth Science, Astronomy, and Space Science at the school level", which aims to help pre-service science teachers learn and understand foundational concepts, theories, and principles related to earth science, astronomy, and space science, as well as to effectively receive and communicate knowledge as part of the learning process, the following observations were made. This course, offered in the previous academic year as part of the science teacher education program, revealed that most pre-service science teachers in the class had average academic performance and exhibited misconceptions. Similarly, Ibrahim, Yusof, Zulkipli, and Dalim (2021) [18] found that pre-service teachers in Malaysia held misconceptions in space science, particularly about basic astronomy concepts such as the formation of the seasons, the causes of day and night, and the galaxy. Likewise, Akcanca and Özsevgeç (2020) [19] reported that although Turkish pre-service teachers' misconceptions in Earth and space science decreased after learning with various teaching methods, some misconceptions persisted. These misconceptions will likely affect their science communication skills, leading to the incorrect conveyance of concepts. In presentations, they were unable to select or interpret learning media appropriately. They also failed to summarize classroom activities effectively or connect classroom knowledge to explain phenomena or communicate concepts accurately. Therefore, it is crucial for pre-service science teachers to regularly improve their science communication skills, both in speaking and writing. Additional data showed that some pre-service teachers held incorrect scientific concepts, which varied depending on their knowledge levels [20]. These misconceptions could negatively impact their science learning achievements [21]. Consequently, enhancing pre-service science teachers' science communication skills must also involve improving their overall science learning achievements [22, 23].

Promoting the science communication skills of pre-service science teachers can be achieved through activities such as integrating experimental activities and fostering critical thinking [16], as well as using inquiry-based learning combined with communication methods [24, 25]. Previous research has identified various forms of inquiry-based learning. However, the 5Es inquiry-based learning model has been reported to be used alongside other techniques to specifically promote science communication skills [25]. The 5Es model supports learners in constructing scientific explanations based on empirical evidence and effectively communicating those explanations [26]. Moreover, the 5Es inquiry-based learning model has been proposed as a primary teaching method in Thai science classrooms, emphasizing its importance for all science teachers to become familiar with. While inquiry-based learning can develop the science communication skills of both upper secondary school students and science teachers, learners often face challenges in constructing explanations and linking explored knowledge to scientific concepts. Though inquiry-based learning promotes the ability to construct scientific explanations and investigate empirical evidence, additional strategies are necessary to help learners effectively communicate information using reasonable and sufficient evidence [24].

Communication strategies refer to instructional techniques used in language education to help learners convey information effectively and achieve specific objectives [27]. These strategies can involve both verbal and nonverbal methods [28-30]. Although previous literature on science teaching and learning has not extensively explored the use of communication strategies, integrating them with scientific communication can promote the development of learners' science communication skills. Given that science communication skills are grounded in effective communication, employing communication strategies can enhance learners' abilities to transfer and interpret scientific data and phenomena [1, 2, 4, 31].

In this research study, we revised the inquiry-based learning model to integrate communication strategies aimed at promoting pre-service science teachers' science communication skills and learning achievements. The model was based on the 5Es of inquiry-based learning [26] and incorporated communication strategies to enhance science communication skills through three specified components: (1) summarizing scientific concepts, (2) interpreting data using scientific evidence, and (3) explaining scientific phenomena. The 5Es inquiry-based learning model was utilized, with communication strategies integrated into each step. The exploration step focused on concluding the scientific main concepts, the explanation step involved interpreting information with scientific and empirical evidence, and the elaboration step involved expanding on scientific phenomena. Modified names for the learning steps were used to clarify the science learning model and promote both science communication skills and learning achievements.

Literature review

Science Communication Skills

Science communication skills are the ability to transfer scientific knowledge through various modes of communication, including listening, reading, writing, and speaking [7, 12]. These skills involve conveying scientific concepts and ideas using accurate terminology, vocabulary, and symbols [14]. In this study, the focus is on speaking and writing skills because they are closely linked to listening and reading skills [2, 31, 32]. The science communication skills in this study were synthesized based on the components outlined in the Programme for International Student Assessment (PISA) 2015 science framework, as defined by the Organisation for Economic Cooperation and Development (OECD) (2015) [33]. Since science was the main subject assessed in PISA 2015, the framework's clear definition of scientific literacy and its components provide a comprehensive and consistent basis for identifying individuals with proficient science communication skills. Furthermore, the framework is widely recognized and robust, making it highly suitable for identifying the science communication skills of pre-service science teachers in this study. While the components remain the same, the criteria have been adjusted to better align with the abilities that pre-service science teachers should possess. Science teachers, as the primary group in need of development into scientifically literate individuals, must acquire these skills to accurately and completely convey scientific knowledge to students. Scientific literacy is crucial for effective science education, as it enables teachers to communicate scientific and technological knowledge logically and thoroughly, thereby maximizing their potential in developing these essential skills. The science communication skills in this study are divided into three components: (1) summarizing scientific concepts, which involves accurately and reasonably speaking and writing about findings from inquiry processes such as searching, experimenting, and creating products, as well as creating scientific content, information, and issues; (2) interpreting data using scientific evidence, which involves using scientific knowledge to clearly and correctly explain information or relationships among information, figures, formulas, tables, vocabularies, and symbols; and (3) explaining scientific phenomena, which involves clearly and correctly expressing scientific knowledge, ideas, and concepts in relation to daily or real situations and phenomena. Science communication skills can be assessed using tests that measure communication performance, particularly in writing and speaking. These tests include situations where learners are required to respond to specific questions in writing or speaking. The assessment criteria are clearly defined for pre-service science teachers, outlining the skills they should possess for teaching future students, with specified scoring levels and detailed, question-specific responses [34]. This guideline has been adapted to develop the science communication skills tests used in this research.

The Synthesis of Communication Strategies

Communication strategies are techniques used by language learners to overcome communication barriers caused by limitations in their linguistic abilities. The synthesis of communication strategies for promoting science communication skills involves six strategies: (1) Description task [35, 36], (2) Exemplification, (3) Superordinate [35], (4) Repetition, (5) Comprehension checking, and (6) Using representations [37]. Science teachers use communication methods similar to these strategies. These methods include explaining scientific concepts, using examples to link scientific knowledge to real-world events, classifying information to help learners analyze and categorize it, repeating information to aid learners in analyzing and interpreting it, reviewing knowledge and understanding with learners, and using learning representations.

To synthesize communication strategies that promote science communication skills, we consider the six aforementioned strategies and essential features extracted from the instructional and learning models promoting science communication skills including problem-based learning, flipped classroom learning [38], activity-based learning [16, 39-40], inquiry-based learning [24, 25], and socio-scientific issues-based learning [41]. Essential features of learning models promoting science communication skills are: (1) promoting learners to communicate scientific conclusions from their activities through speaking and writing [16, 24, 25, 38-40], (2) promoting learners to link prior knowledge to new knowledge from findings to explain phenomena or real-world situations [24, 25, 41], and (3) promoting learnerคs to use scientific knowledge to explain information through figures, formulas, words, scientific symbols, and other representations [16, 24, 25, 38-40]. Table 1 presents a synthesis of communication strategies for promoting science communication skills.

Table 1 The synthesis of the communication strategies to promote science communication skills

Communication strategies in linguistic	Essential features of the learning model promoting science communication skills	Communication strategies for science communication skills
1. Repetition 2. Comprehension checking	Promoting learners to communicate scientific conclusions from their activities through speaking and writing	Scientific inference
3. Description task 4. Exemplification 5. Superordinate	Promoting learners to link prior knowledge to new knowledge from findings to explain phenomena or real-world situations	Analytical lecturing
6. Using representations	Promoting learners to use scientific knowledge to explain information through figures, formulas, words, scientific symbols, and other representations	Using visual representations

The synthesis of communication strategies for promoting science communication skills consists of three main strategies: scientific inference, analytical lecturing, and using visual representations. Each strategy is defined based on the essential features of science learning models that promote science communication skills.

Scientific inference is a strategy that encourages learners to link their knowledge from findings to prior knowledge, which enables them to acquire new knowledge. This is achieved by presenting knowledge in classrooms and concluding scientific issues in activity forms, thereby promoting the science communication skill of summarizing scientific concepts.

Analytical lecturing is a strategy that encourages learners to connect their scientific knowledge to prior knowledge, daily situations, and scientific phenomena. This is achieved by presenting knowledge in classrooms or providing examples to explain scientific principles and reasons in activity forms, thereby promoting the science communication skill of explaining scientific phenomena.

Using visual representations is a strategy that encourages learners to use empirical, scientific information and evidence derived from findings to explain the relationships of information in various forms such as figures, tables, graphs, formulas, words, and scientific symbols. This strategy promotes the science communication skill of interpreting data using scientific evidence.

Methods

In this research study, a learning model was developed to promote science communication skills for future science teachers, using a research and development process simplified into four steps as follows:

Step 1: Review relevant documents and fundamental concepts (R_1)

The research question, goal, and findings of this step are as follows:

Research question: What educational policies and theoretical foundations are relevant to the development of a learning model that promotes pre-service science teachers' science communication skills?

Research goal: To synthesize relevant educational policies, theories, and concepts to design a learning model for developing pre-service science teachers' science communication skills.

Research findings: The findings include concepts related to educational policies, science communication skills, theories of science learning model development, instructional models and methods for promoting science communication skills, inquiry-based learning, and communication strategies. These findings provided the foundation for the learning model design.

Step 2: Develop the learning model and research instruments (D_1)

This involved creating the learning model based on the knowledge gained from Step 1 and three research instruments: (1) eight lesson plans for earth science, astronomy, and space science concepts including 1) seasons 2) waxing moon 3) rocks and minerals 4) fuels, fossils and renewable energy 5) Earth's structure 6) soil 7) atmosphere and 8) humidity, that took three hours per lesson plan, (2) eight science communication skills tests (including writing and speaking skills), and (3) a learning achievement multiple-choice test with 40 items that were used as both a pre-test and a post-test.

In developing the learning model, the researcher conducted a detailed study of relevant concepts, including the concept of inquiry-based learning and the concept of learning through communication strategies. The 5Es inquiry-based learning model [26] can support the development of science communication skills, particularly through three steps: step 2 (exploration), step 3 (explanation), and step 4 (elaboration). The researcher synthesized three communication strategies—scientific inference, analytical lecturing, and using visual representations—and incorporated them into the inquiry-based learning model. Scientific inference was integrated into step 2 (exploration). Analytical lecturing, a strategy that facilitates students' communication of their knowledge, was incorporated into both step 3 (explanation) and step 4 (elaboration). The use of visual representations, which involves explaining scientific concepts using various types of symbols, was added to step 3 (explanation). To ensure that each step effectively promotes the development of science communication skills in alignment with its components, the names of steps 2, 3, and 4 were revised accordingly. This comprehensive approach resulted in a learning model that can effectively promote the development of science communication skills, as shown in Table 2.

Table 2 The development of the learning model to promote science communication skills.

Learning model	Learners' behaviors	Synthesized communication strategies	Science communication skills
1. Engagement	- The learners are interested in situations and communication in order to ask questions based on their observations.	-	-
2. Exploration and inference	- The learners engage in group activities, make plans, specify steps for data searching, and take action based on evidence.	Scientific inference	Summarizing scientific concepts
3. Logical explanation	- The learners link the collected knowledge to their prior knowledge to draw new conclusions, and provide explanations based on the information and evidence. - The learners communicate their knowledge to their classmates and instructors through clear and correct speaking and writing, using scientific concepts and principles.	- Analytical lecturing - Using visual representations	- Interpreting the data using scientific evidence - Explaining scientific phenomena
4. Analytical elaboration	- The learners link prior knowledge to new knowledge to explain daily situations and communicate that knowledge clearly according to scientific principles.	Analytical lecturing	Explaining the scientific phenomena
5. Evaluation	- The learners evaluate their own progress after each lesson. - The learners ask instructors about any issues they still have doubts about.	-	-

The learning model and eight lesson plans were verified by three experts to check the content and construct validity evidences. The index of consistency was in the range of 0.67-1.00. Based on the experts' comments and suggestions, the researchers revised the model and lesson plans. Figure 1 illustrates the science learning model developed by combining inquiry-based learning with communication strategies to promote science communication skills.

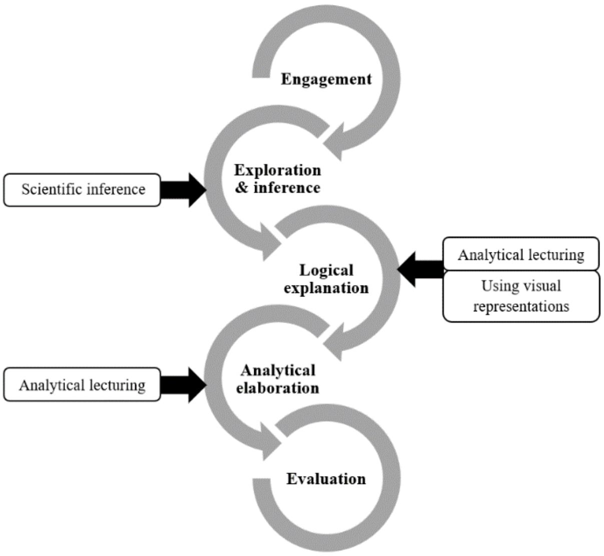

Figure 1 Inquiry-based learning model to promote science communication skills

The science communication skills writing test consists of two parts; (1) a situation related to the scientific content studied and (2) an open-ended question. In speaking skills test, requires students to discuss the same topic as the written test, recording both video and audio responses. The evaluation uses a five-level rubric with scores of 5, 4, 3, 2, and 1. The total score is 15, divided into five performance levels: excellent (13–15 points), good (10–12 points), moderate (7–9 points), fair (4–6 points), and needs improvement (0–3 points). Example of a situation, a question and the first component of science communication skills criteria are as follows.

Situation: The weather conditions in two locations on Earth during the same period: London, England, in December, where the weather is snowy, and Bangkok, Thailand, in December, where the weather is hot and humid.

Question: Explain why these two countries experience different seasons in December.

Criteria:

Component	Level of science communication skills				
	Excellent (5)	Good (4)	Moderate (3)	Fair (2)	Needs Improvement (1)
1. Summarizing scientific concepts	- Provides a fully accurate and complete explanation based on scientific principles. - Cites at least two reasons from findings in activities.	- Provides a fully accurate and complete explanation based on scientific principles. - Cites at least one reason from findings in activities.	- Provides an accurate but incomplete explanation based on scientific principles. - Cites at least one reason from findings in activities.	- Provides an accurate but incomplete explanation that does not fully adhere to scientific principles. - Cites at least one reason not derived from findings in activities.	- Provides an inaccurate and incomplete explanation that does not adhere to scientific principles. - Provides no references to reasoning.

Figure 2 Example of science communication skills test and criteria.

The learning achievement test is a multiple-choice test with four options per question, comprising a total of 40 questions. Correct answers are awarded one point, while incorrect answers receive zero points. The test covers eight topics as mentioned earlier.

The science communication skills and learning achievement tests were tried out with 24 pre-service science teachers to assess the quality of the tests. The reliability of the eight science communication skills was high, with Cronbach's alpha coefficients ranging from 0.81-0.95. The difficulty indices of the learning achievement test ranged from 0.23-0.80, and the discriminant indices were between 0.40-0.67. The KR-20 reliability was 0.64.

Step 3: Pilot (R_2) and revise the learning model (D_1)

The research questions, goal, and findings of this step are as follows:

Research question: 1) How effective is the initial learning model in promoting science communication skills and learning achievement? And 2) what improvements can be made to refine the instructional sequence and learning activities?

Research goal: To evaluate the initial learning model's implementation and effectiveness in a pilot study, collect feedback, and revise the model for the main study.

Research findings: The model was piloted with 24 pre-service science teachers who were not part of the main participants. These participants had previously completed coursework in "Earth Science, Astronomy, and Space Science at the school level". The pilot employed three lesson plans over a total of nine hours to evaluate the sequence of instruction, learning activities, and problems during implementation. This process aimed to refine the model before its application in the main study. Since these pre-service teachers had prior experience in the subject, they could provide valuable feedback on the learning activities, enabling adjustments to enhance the model's effectiveness for the target study group. Data were collected using tests measuring science communication skills and learning achievement. The learning model was subsequently revised based on these results and the assessment criteria of the tests.

Step 4: Implement the learning model (R_3 and D_3)

The research question, goal, and findings of this step are as follows:

Research question: How effective is the revised learning model in developing science communication skills and improving learning achievement among pre-service science teachers?

Research goal: To implement the revised learning model with the participants, assess its effectiveness in enhancing science communication skills and learning achievement.

Research findings: The revised model was implemented with the participants, consisting of 25 third-year pre-service science teachers from the Faculty of Education at a Rajabhat University during the second semester of the 2020 academic year. The participants were selected through purposive sampling as they had no prior experience to this subject, ensuring the model's effectiveness in developing science communication skills and learning achievement. A pre-test of learning achievement was conducted for one hour, followed by implementing the eight lesson plans. After each lesson, students took science communication skills tests, and the post-test parallel to the pre-test was conducted for one hour.

For data analysis, mean and standard deviation were used to analyze pre-service teachers' science communication skills in each lesson plan, focusing separately on writing and speaking skills. Moreover, these were used to compare writing and speaking skills across eight lessons. The relative gain scores, frequencies, and percentages were calculated for writing skills, speaking skills, and overall performance to represent the development levels of pre-service teachers' science communication skills. The achievement pre- and post-test mean scores were compared using a dependent t-test.

Results and Discussion

The effectiveness of the redesigned inquiry-based learning model composed of five steps including (1) engagement, (2) exploration and inference, (3) logical explanation, (4) analytical elaboration, and (5) evaluation was examined for learning science in actual contexts. There were several reasons that supported the effectiveness of the model. Firstly, the model was developed based on the basic concepts of learning, including inquiry-based learning, and used the 5Es of inquiry-based learning as the basic steps [26]. In addition, the model synthesized three communication strategies, namely scientific inference, analytical lecturing, and using visual representations, to promote science communication skills. Secondly, the model clearly defined and assigned practical roles to instructors and learners in each step of the learning process. This was consistent with the concept of learning model development proposed by Grau et al. (2021) [42], Joyce and Weil (1986) [43], and Mueller et al. (2015) [44] which emphasized the importance of clear-cut steps, methods, and techniques for efficient learning. Moreover, Fadli & Irwanto (2020) [45] and Lehtinen et al. (2017) [24] found that a learning model with clear and practical roles for related individuals could improve pre-service science teachers' skills after learning. Finally, the learning model was piloted and evaluated to ensure the appropriateness of its contents, activities, duration, learning representations, and evaluations. This is in line with Bahtiar et al.'s (2017) [46] suggestion that the effectiveness of a learning model could be improved by checking the quality of each component and piloting the model before its actual implementation. The results obtained from using the science learning model to promote science communication skills can be summarized in terms of (1) science communication skills and (2) science learning achievements

Science communication skills

The pre-service science teachers' mean scores in science communication writing skills tended to increase in each test. In the 1st test, the mean score was 7.60 (S.D. = 2.54), indicating a moderate level of proficiency. In the 2nd, 3rd, and 4th tests, the mean score improved to 10.60 (S.D. = 1.31), 12.20 (S.D. = 1.22), and 12.20 (S.D. = 1.55), respectively, indicating a good level of proficiency. In the 5th, 6th, 7th, and 8th tests, the mean score further improved to 13.20 (S.D. = 1.37), 13.52 (S.D. = 1.08), 13.24 (S.D. = 1.19), and 13.44 (S.D. = 1.70), respectively, indicating a very good level of proficiency. The mean scores for each of the three writing skill components; (1) summarizing scientific concepts, (2) interpreting data using scientific evidence, and (3) explaining scientific phenomena were analyzed for the eight tests, and their trends are presented in Figure 3.

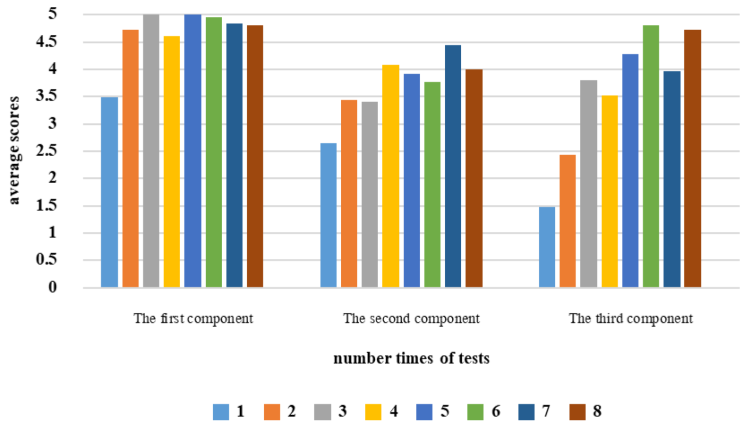

Figure 3 The mean score of the writing skill in each component from the eight tests.

In each science communication speaking skills test, the pre-service science teachers' mean scores demonstrated a trend of improvement. The initial mean score for the 1st test was 8.08 (S.D. = 2.83) at the moderate level. The mean score then increased for the 2nd, 3rd, and 4th tests, with a mean score of 11.40 (S.D. = 1.47), 11.96 (S.D. = 1.58), and 13.48 (S.D. = 1.31) respectively, at the good level. For the 5th, 6th, 7th, and 8th tests, the mean score further improved to 13.48 (S.D. = 1.27), 14.12 (S.D. = 0.98), 13.40 (S.D. = 1.30), and 14.04 (S.D. = 1.07), respectively, at the very good level. The mean scores of the speaking skills were analyzed for the three components across the eight tests, and the trends of development are shown in Figure 4.

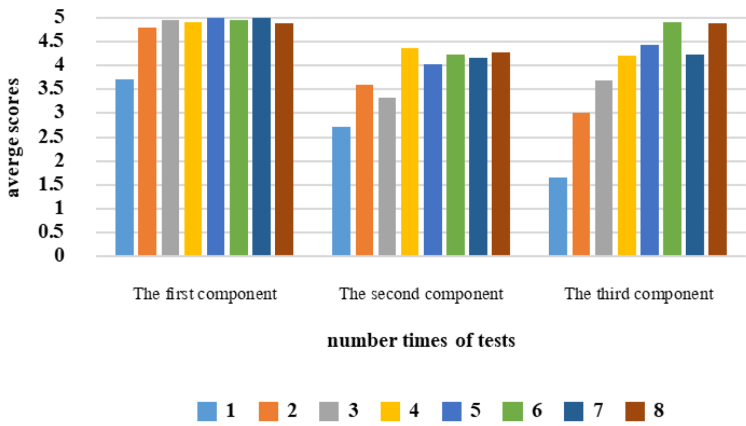

Figure 4 The mean score of the speaking skill in each component from the eight tests.

Based on the situation and question in the previous section (Step 2: Develop the learning model and research instruments), the following are examples of responses at excellent and fair levels for the first component of science communication skills in both writing and speaking:

Example of a response with an excellent level

"*London, England, experiences snowfall, indicating winter. Winter occurs because the Earth's axis in the Northern Hemisphere tilts away from the Sun, receiving oblique sunlight, which leads to the lowest temperatures. Conversely, Bangkok, Thailand, experiences hot and humid weather, indicating summer. Summer occurs when the Earth's* *axis in the Southern Hemisphere tilts toward the Sun, receiving direct sunlight, resulting in the highest temperatures. Therefore, despite being in the same month of December, differences in the angle of sunlight between the Northern and Southern Hemispheres lead to varying temperatures and seasonal differences.*" (Pre-service science teacher A)

For the component 1 summarizing scientific concepts," this response accurately and presents information derived from the activity, supported by at least two reasons; (1) winter occurs due to the Earth's axis in the Northern Hemisphere tilting away from the Sun, receiving oblique sunlight, and (2) oblique sunlight results in significantly lower temperatures. This response received 5 points according to the criteria.

Example of a response with a fair level

"Snow begins to form when atmospheric temperatures drop below freezing. If the temperature remains below freezing all the way to the ground, snow will form. Areas where snow falls must be located above 23.5° latitude, either north or south, mostly in Europe and North America, leading to snowfall in winter. Bangkok, Thailand, is located at 13°N latitude, below 23.5°N, in a tropical region with a hot and rainy climate year-round, unsuitable for snow formation. In contrast, London, England, is at 31°N latitude, above 23.5°N, in a temperate zone leaning toward a cold climate, making snowfall possible in winter." (Pre-service science teacher B)

For the component 1 summarizing scientific concepts," this response provides only one reason, citing the latitude difference between the two locations as the cause of differing climates. However, this reason does not derive from the activity findings and is not entirely accurate or clear. This response received 2 points according to the criteria.

The pre-service science teachers' science communication skills were evaluated through eight tests, including writing and speaking tasks. Overall, their mean scores tended to increase throughout the study. The analysis of the three components of science communication skills, summarizing scientific concepts, interpreting data using scientific evidence, and explaining scientific phenomena, showed that the pre-service science teachers had the highest mean scores in the first component for both writing and speaking skills. In class, the pre-service science teachers were divided into eight groups, three people per group. They always had to write and speak in order to communicate scientific knowledge. During the first lesson plan, it was found that many pre-service science teachers struggled to draw precise scientific conclusions and select appropriate representations to convey their findings. As a result, the communicated information lacked well-arranged content [39, 41, 47]. As the pre-service science teachers progressed through the second and third lesson plans, their science communication skills improved due to their understanding of the learning processes and activities such as experiments, observations, virtual experiments, and online media [16]. The instructors facilitated the students' ability to brainstorm, discuss and share knowledge in their groups, and provided guidelines to prepare for presentations and record experimental results [24]. By the 4th to 8th lesson plans, the pre-service science teachers' skills had reached a very good level due to the clear learning processes and continuous support from instructors. However, the mean scores in tests 4-8 varied due to differences in students' skills and interests in topics [20]. Levy et al. (2009) [8] found that students with different scientific knowledge would have opportunities to apply science communication skills in different contexts.

In comparing writing and speaking skills across eight lessons, it was found that Pre-service science teachers' average speaking scores exceeded their writing scores in seven lessons (Lessons 1, 2, 4, 5, 6, 7, and 8). Only in lesson plan 3, focused on "Fossil fuels and renewable energy," were the writing scores higher. During the implementation of lesson plan 3, observations revealed that they spent more time on the activities than in other lessons. Many of them asked questions for clarification, with some struggling to communicate their points effectively. Several of them remarked that the topic was particularly difficult to understand. The tendency for speaking scores to be higher than writing scores in other lessons may be because of students completing the writing tasks first. Writing serves as a framework for organizing and clarifying ideas before specking. This process allows students to review and refine their written answers. Therefore, when transitioning to the speaking tasks, students effectively communicate the same information in a more polished form, benefiting from their prior written work. Moreover, if students' written responses were incomplete or contained errors, they could address these issues during their speaking tasks, leading to more comprehensive and accurate communication.

The pre-service science teachers' relative gain scores for writing skills, speaking skills, and overall skills after learning with the developed learning model in eight lesson plans were analyzed. The scores were obtained from eight tests, and the total score for each test was 15. The relative development levels for writing skills, speaking skills, and overall skills were classified into seven phases, from the 1st to the 7th phase. The results showed that students in the 1st phase had an average development percentage of 37.79 at the moderate level. In the 2nd, 3rd, 4th, 5th, and 6th phases, the average development percentages were 57.56, 58.68, 73.16, 75.77, and 73.74, respectively, at the high level. In the 7th phase, the students' average development percentage was 77.63 at a very high level.

Regarding speaking skills, the students in the 1st phase had an average development percentage of 45.54 at the moderate level. For the 2nd phase, the students' average development percentage was 52.74 at the high level. For the 3rd, 4th, 5th, 6th, and 7th phases, the students' average development percentages were 78.07, 78.61, 87.19, 71.30, and 84.90, respectively, at a very high level. For overall development, the students in the 1st phase had an average development percentage of 41.99 at the moderate level. For the 2nd and 3rd phases, the students' average development percentages were 55.35 and 68.16, respectively, at the high level. For the 4th, 5th, 6th, and 7th phases, the students' average development percentages were 75.97, 78.80, 76.63, and 81.39, respectively, at a very high level. The writing skills were divided into five development groups, and the speaking skills were divided into seven development groups. The overall skills were also divided into five development groups, as shown in Table 3.

Table 3 Number of learners and percentages in each of the relative gain scores levels

Relative gain scores levels	Writing skills		Speaking skills		Overall	
	Number	%	Number	%	Number	%
Low - High	5	20.00	3	12.00	3	12.00
Low – Very high	1	4.00	1	4.00	1	4.00
Moderate – Moderate	3	12.00	-	-	-	-
Moderate – High	2	8.00	5	20.00	6	24.00
Moderate – Very high	14	56.00	10	40.00	12	48.00
High – High	-	-	1	4.00	-	-
High – Very high	-	-	4	16.00	3	12.00
Very high – Very high	-	-	1	4.00	-	-

After considering all seven phases of development, it became evident that the mean score and development scores in each phase significantly increased. This was due to the inquiry-based learning model based on the 5Es and communication strategies that served as guidelines for students to develop their skills. Each strategy stimulated the students to communicate scientific knowledge using both speaking and writing skills. Regarding writing skills, the levels in the 1st and 7th phases could be classified into five development groups: low-high, low-very high, moderate-moderate, moderate-high, and moderate-very high. Three pre-service science teachers maintained their moderate level skills, while in phases 2-6, the remaining students improved their skills to high and very high levels. The inconsistency in skill levels may have been due to differences in student knowledge and understanding, as well as attention levels during tests. This is consistent with Goldberg et al.'s (2021) [48] study, which indicated that student attention during tests affected their scores. For science communication speaking skills, there were seven development groups, including three new ones: high-high, high-very high, and very high-very high. Six students initially had high or very high speaking skills, and four students improved from high to very high levels. One student maintained a very high level throughout. Overall, the group with basic scores at the high and very high levels in the 1st phase consisted of only four students, but these students maintained their high levels throughout all eight phases of learning. A limitation of the developed learning model is that, according to the research findings, it was more effective in enhancing science communication skills in speaking compared to writing. To address this, instructors should place greater emphasis on reviewing and verifying students' written responses during the learning process. Students should be guided to write accurately and comprehensively before using the information for verbal communication.

Science learning achievement

The analysis of the pre-test and post-test mean scores for science learning achievement revealed that the students' post-test mean scores were significantly higher than their pre-test scores at a 0.05 level of statistical significance, as presented in Table 4

Table 4 Comparison of science learning achievement pre-test and post-test mean scores

Tests	n	Total scores	M	S.D.	t	p
Before learning	25	40.00	19.84	2.52	-15.19*	0.000
After learning	25	40.00	30.88	3.77		

* $p < .05$

The mean scores of science learning achievement for pre-service science teachers who learned with the science learning model were significantly higher than before learning, at a significance level of .05. This can be attributed to several factors. Firstly, each step of the learning model was designed to improve learning achievements. In step 1, engagement, students were required to ask questions, express opinions, and use prior knowledge to understand new information. In step 2, exploration and inference, students had to communicate scientific content and issues clearly and reasonably, drawing on inquiry processes and prior knowledge. Step 3, logical explanation, focused on using evidence and data to create scientific explanations, with students speaking and writing about scientific concepts, using figures, tables, formulas, and scientific symbols. Step 4, analytical elaboration, helped students link new knowledge to prior knowledge and situations, thereby improving learning outcomes. Finally, step 5, evaluation, allowed students to assess themselves and their peers, while instructors evaluated student performance. Science learning achievement can be promoted by developing science communication skills, according to previous studies [22, 23]. Aydln (2016) [49] and Purnomoa and Fauziah (2018) [50] found that students with higher learning achievements usually have good communication skills, able to speak about scientific conclusions and use effective communication methods to explain scientific concepts. Secondly, the developed science learning model utilizes inquiry-based learning as the basis for creating a learning model. Previous studies have confirmed that inquiry-based learning can improve science learning achievement [21, 42, 51]. By encouraging students to search for answers, practice, make observations, analyze information, and share knowledge, inquiry-based learning stimulates students to develop understanding, link knowledge, and gain experience, leading to better learning outcomes [21, 42].

Based on the above evidence, it is clear that this research study has developed a highly beneficial science learning model for pre-service science teachers. This redesigned inquiry-based learning model enhances their science communication skills and improves their learning achievement in the classroom, enabling them to transfer scientific knowledge to their students more efficiently. However, one notable limitation of this study is the small number of participants. This limitation affects the generalizability of the results, as the sample may not fully represent diverse educational contexts. Future research should address this issue by involving larger, more diverse samples across multiple institutions. Doing so would provide a more comprehensive evaluation of the model's effectiveness and adaptability, ensuring its relevance across varied educational settings.

Conclusion

This research study presents a redesigned inquiry-based learning model composed of five steps that was found to be beneficial for enhancing pre-service science teachers' science communication skills and learning achievement. The redesign addresses the significant challenge of effectively integrating communication strategies within the inquiry-based framework, ensuring that the model not only fosters deep scientific understanding but also hones the ability to communicate complex concepts clearly and confidently. The learning model, grounded in both inquiry-based learning and tailored communication strategies, is versatile and can be applied in both online and on-site classroom contexts. In online learning contexts, it is recommended that teachers prepare learning materials that include experimental demonstration videos and virtual classroom programs, and encourage students to interact with classmates to exchange knowledge and evaluate results of knowledge communication. While the study demonstrates the efficacy of this enhanced learning model, it also highlights the inherent challenge of maintaining consistent skill development across different phases. Some students experienced fluctuations in mean scores for each stage of development, indicating that science communication skills are not always stable throughout the learning process. This variability underscores the complexity of teaching science communication and the necessity of ongoing refinement. To gain a more in-depth understanding of students' scientific communication behavior and to identify potential areas for improvement in the learning model, future qualitative research should be conducted.

Ethical Approval

The study is under the ethical standards of human research ethics. The Human Research Ethics Committee of Srinakharinwirot University in Thailand has approved the human research ethics for this study (Certificate number: SWUEC/E/G-042/2564).

Acknowledgements

The authors would like to express their sincere gratitude to all collaborators and the pre-service science teachers from Phranakhon Si Ayutthaya Rajabhat University for their invaluable participation in this study. Special thanks are extended to the Science Education Center, Faculty of Science, Srinakharinwirot University, for their support in providing crucial documentation and assistance throughout the process.

References

1. Haixin D, Liam KB. Scientific conclusions need not be accurate, justified, or believed by their authors. Synthese. 2021;199(3-4):8187-203.
2. Mercer-Mapstone L, Kuchel L. Core skills for effective science communication: a teaching resource for undergraduate science education. Int J Sci Educ B. 2015;7(2):1-21.
3. National Academy of Sciences. The science of science communication III (SSCIII): inspiring novel collaborations and building capacity. Washington (DC): National Academies Press (US); 2017.
4. National Academies. Communicating science effectively: a research agenda. Washington (DC): National Academies Press (US); 2017.
5. National Curriculum. Handbook for secondary teachers in England key stages 3 and 4. London: Department for Education and Skills; 2004.
6. Fischhoff B. Evaluating science communication. Proc Natl Acad Sci USA. 2019;116(16):7670-5.

7. Welgold M, Treise D, Rausch P. Science communication scholarship: themes and future directions. In: Welch-Ross MK, Fasig LG, editors. Handbook on communicating and disseminating behavioral science. London: Sage Publications, Inc.; 2007.
8. Levy OS, Eylon B, Scherz Z. Teaching scientific communication skills in science studies: does it make a difference. Int J Sci Math Educ. 2009;7(5):875-903.
9. Wirz CD, Cate A, Brauer M, Brossard D, Brown LD, Chen K, et al. Science communication during COVID-19: when theory meets practice and best practices meet reality. J Sci Commun. 2022;21(03):1-22.
10. Bultitude K. The why and how of science communication. In: Rosulek P, editor. Science Communication. Pilsen, Czech Republic: European Commission; 2011.
11. Saiquan H, Zhengfeng L, Zhang J, Junming Z. Engaging scientists in science communication: the effect of social proof and meaning. J Clean Prod. 2018;170:1044-51.
12. Hardianti RD, Taufiq M, Pamelasari SD. The development of alternative assessment instrument in web-based scientific communication skill in science education seminar course. J Unnes. 2017;6(1):123-9.
13. Ihmeideh FM, Al-Omari AA, Al-Dababneh KA. Attitudes toward communication skills among students-teachers in Jordanian public universities. Aust J Teach Educ. 2010;35(4):1-11.
14. Jamieson KH, Kahan D, Scheufele DA. The Oxford handbook of the science of science communication. USA: Sheridan Books, Inc; 2017.
15. Office of the Education Council. The national scheme of education B.E. 2560-2579 (2017-2036). Bangkok: Prigwan Graphic; 2018. (in Thai)
16. Malik A, Setiawan A, Suhandi A, Permanasari A, Dirgantara Y, Yuniarti H, et al. Enhancing communication skills of pre-service physics teacher through HOT lab related to electric circuit. Proc Int Jt Conf Sci Technol. 2017;953(012017):1-8.
17. Suwansil P, Pruekpramool C. The views of university supervisors and school advisors related to science communication skills of Rajabhat university's pre-service science teachers. Research Community and Social Development Journal. 2022;16(2):205-18. (in Thai)
18. Ibrahim N, Yusof MMM, Zulkipli ZA, Dalim SF. Pre-service teachers' conceptual understanding in space science. Int J Asian Soc Sci. 2021;11(3):177-87.
19. Akcanca N, Özsevgeç LC. Effect on academic achievement and misconceptions of pre-service teachers through combining different teaching methods in a preschool science course. J Sci Learn. 2020;4(1):41-9.
20. Bray B, France B, Gilbert JK. Identifying the essential elements of effective science communication: what do the experts say?. Int J Sci Educ Part B Commun Public Engagem. 2011;2(1):23-41.
21. Hicks JK, Christmann EP. A comparative analysis of preservice science teachers' college achievement. Int J Inf Educ Technol. 2019;9(8):525-9.
22. Wardani DS. Relationship between teachers' interpersonal communication skills and students' achievement in science at Muhammadiyah primary schools in Sidoarjo district. Proc Asian Conf Educ Int Dev. 2017:427-35.

23. Levy OS, Eylon B, Scherz Z. Teaching communication skills in science: tracing teacher change. Teach Teach Educ. 2008;24(2):462-77.
24. Lehtinen A, Lehesvuori S, Viiri J. The connection between forms of guidance for inquiry-based learning and the communicative approaches applied - a case study in the context of pre-service teachers. Res Sci Educ. 2017;49(6):1547-67.
25. Silpachai N, Panprueksa K, Singlop S. The study of learning achievement, science communication skills and teamwork skills on structure and function of angiosperms using 5e learning cycle with cooperative learning. Journal of Education and Social Development. 2020; 13(1): 169-82. (in Thai)
26. Bybee RW, Taylor JA, Gardner A, Van Scotter P, Powell JC, Westbrook A, et al. The BSCS 5E instructional model: origins and effectiveness. Bethesda, MD: Office of Science Education, National Institutes of Health; 2006.
27. Tarone E. Some thoughts on the notion of communication strategy. TESOL Q. 1981;15(3):285-95.
28. Canale M. From communicative competence to communicative language pedagogy. In: Richards JC, Schmidt R, editors. English for Cross-Cultural Communication. New York: Longman; 1983.
29. Brown HD. Principles of language learning and teaching. 5th ed. Englewood Cliffs, NJ: Prentice Hall; 1987.
30. Al-garabel S, Dasi C. The definition of achievement and the construction of tests for its measurement: a review of the main trends. Psicología Universidad de Valencia. 2001;22(1):43-66.
31. Mercer-Mapstonea LD, Matthews KE. Student perceptions of communication skills in undergraduate science at an Australian research-intensive university. Assess Eval High Educ. 2015;4(1):1-17.
32. Alpusari M, Mulyani EA, Putra ZH, Widyanthi A, Hermita N. Identifying students' scientific communication skills on vertebrata organs. J Phys Conf Ser. 2019;1351:1-7.
33. Organization for Economic Cooperation and Development. PISA 2015 item submission guidelines: scientific literacy. 2015.
34. Kulgemeyer C, Schecker H. Students explaining science—assessment of science communication competence. Res Sci Educ. 2013;43:2235–56.
35. Faerch C, Kasper G. Plans and strategies in foreign language communication. In: Faerch C, Kasper G, editors. Strategies in Interlanguage Communication. New York: Longman; 1983.
36. Varadi T. Strategies of target language learner communication: message adjustment. In: Faerch C, Kasper G, editors. Strategies in interlanguage communication. London: Longman; 1983.
37. Dornyei Z, Scott ML. Communication strategies in a second language: definitions and taxonomies. Lang Learn. 1997;47(1):173-210.
38. Teachakaew S, Kijkuakul S, Booncham U. Develop flipped classroom for encourage science communication skills in nervous system and structure and movement system. Journal of Education Naresuan University. 2017;22(1):262-72. (in Thai)
39. Patriot EA, Suhandi A, Chandra DT. Optimize scientific communication skills on work and energy concept with implementation of interactive conceptual instruction and multirepresentation approach. J Phys Conf Ser. 2018;1013(1):1-7.

40. Garces H, Esther PB. Corporate communication strategies are applicable for teaching non-science communication skills to pharmaceutical sciences PhD students. Curr Pharm Teach Learn. 2015;7(2):265-72.
41. Chung Y, Yoo J, Kim SW, Lee H, Zeidler DL. Enhancing students' communication skills in the science classroom through socioscientific issues. Int J Sci Math Educ. 2016;14:1-27.
42. Grau FG, Valls C, Piqué N, Ruiz HM. The long-term effects of introducing the 5E model of instruction on students' conceptual learning. Int J Sci Educ. 2021;43(9):1441-54.
43. Joyce B, Weil M. Models of teacher. 3rd ed. Prentice Hall; 1986.
44. Mueller AL, Knobloch NA, Orvis KS. Exploring the effects of active learning on high school students' outcomes and teachers' perceptions of biotechnology and genetics instruction. J Agric Educ. 2015;56(2):138-52.
45. Fadli A, Irwanto. The effect of local wisdom-based ELSII learning model on the problem-solving and communication skills of pre-service Islamic teachers. Int J Instr. 2020;13(1):731-46.
46. Bahtiar, Rahayu YS, Wasis. Developing learning model P3E to improve students' critical thinking skills of Islamic senior high school. J Phys Conf Ser. 2017;947:1-7.
47. Robillos RJ. Improving students' speaking performance and communication engagement through technology-mediated pedagogical approach. Int J Instr. 2023;16(1):551-72.
48. Goldberg JM, Sommers-Spijkerman MPJ, Clarke AM, Schreurs KMG, Bohlmeijer ET. Positive education in daily teaching, the promotion of wellbeing, and engagement in a whole school approach: a clustered quasi-experimental trial. Int J Res. 2021;33(1):148-67.
49. AydIn A. Impacts of inquiry-based laboratory experiments on prospective teachers' communication skills. Int Online J Educ Sci. 2016;8(2):49-61.
50. Purnomoa AR, Fauziah ANM. Promoting science communication skills in the form of oral presentation through pictorial analogy. Int Conf Sci Educ. 2018;1006(1):1-8.
51. Maxwell DO, Lambeth DT, Cox JT. Effects of using inquiry-based learning on science achievement for fifth-grade students. Asia Pac Forum Sci Learn Teach. 2015;16(1):1-31.