The Effect of Using the Integrated NOS Instructional Model on Enhancing the Scientific Literacy of Science Student Teachers at Rajabhat University

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Abstract

This quasi-experimental research aimed to enhance the scientific literacy of general science student teachers at a Rajabhat University and to evaluate their opinions toward the implemented integrated Nature of Science (NOS) instructional model. The study employed a one-group pretest-posttest design with 21 third-year general science student teachers from Bansomdejchaopraya Rajabhat University, purposively selected from those enrolled in the "Science Teaching Using Local Wisdom" course during the 2023 academic year. An integrated NOS instructional model, grounded in constructivist principles and comprising six stages (Target, Review, Inquiry, Construct, Apply, and Reflect/Evaluate), was implemented within the course curriculum. Research instruments included an integrated NOS instructional lesson plan, a scientific literacy assessment tool, and an opinion questionnaire, all validated by expert panels. Data analysis utilized descriptive statistics and paired-sample t-tests.

The findings revealed that student teachers who participated in the integrated NOS instructional model achieved significantly higher post-test scientific literacy scores (75.25%) compared to their pre-test scores (61.30%) at the .05 level of statistical significance. The post-test scientific literacy score exceeded the predetermined 75% criterion. Furthermore, students expressed positive opinions toward the integrated NOS instructional model (M = 4.32, SD = 0.54). All four components of scientific literacy—scientific attitude, understanding of the nature of science, scientific inquiry ability, and application of science in context—demonstrated statistically significant improvements. The model's effectiveness was attributed to its constructivist foundation, which enhanced active learning through systematic inquiry and culturally responsive pedagogy. These findings have significant implications for science teacher education programs, suggesting that the integrated NOS instructional model should be widely adopted in Rajabhat Universities and similar institutions to strengthen pre-service teacher preparation and develop scientifically literate educators capable of fostering inquiry-based learning in their future classrooms.

Keywords: Scientific Literacy; Nature of Science (NOS); Constructivism; Integrated Instructional Model; Teacher Education

Introduction

Scientific literacy is the foundational ability of a reflective citizen to engage with science-related issues and apply scientific concepts to navigate an increasingly complex world (OECD, 2019). In an era where science and technology profoundly transform lifestyles, the cultivation of a scientifically literate populace is a paramount objective for nations worldwide (Bybee, 2015; BouJaoude, 2002). In response, many countries have adapted their educational systems to prioritize science education (Fensham, 2005). Thailand has similarly integrated scientific literacy into its basic education core curriculum, aiming to equip citizens with the competencies needed for 21st-century challenges (IPST, 2018).

Despite these efforts, evidence from the Programme for International Student Assessment (PISA) indicates a concerning trend: Thai students' science performance scores are consistently below the international average (OECD, 2019). This suggests a systemic challenge in designing and implementing science education that effectively enhances student learning outcomes. A critical factor in this equation is the teacher, whose instructional quality is a primary determinant of student achievement (Rangabtuk, 2020; Barber & Mourshed, 2007). Educators widely concur that science teachers' own proficiency in scientific literacy is essential for fostering it in their students (Al Sultan et al., 2018; Hanushek et al., 2019; Özdem et al., 2010).

A cornerstone of scientific literacy is a robust understanding of the Nature of Science (NOS), which provides the epistemological foundation for how scientific knowledge is constructed and validated (McComas et al., 2002). However, research reveals that pre-service science teachers in Thailand, particularly those at Rajabhat Universities—institutions historically mandated to support local and national development—often hold naive views and misconceptions about NOS (Songumpai et al., 2017;

Khumruksa & Rakbumrung, 2020). Furthermore, their overall scientific literacy requires significant improvement (Charoenlikitkawin & Chaikit, 2021; El-Islami & Nuangchalerm, 2020; Theppitak, 2024). When these pre-service teachers enter schools for their practicum, they struggle to translate theoretical knowledge into effective classroom practice, often perpetuating the same misconceptions about NOS (Jituafua et al., 2015; Sepkholam & Thiangchantrathip, 2021).

These shortcomings are exacerbated by limitations within traditional science teacher education curricula, which are often characterized by excessive content, fragmented teaching methods, and a failure to integrate NOS in a contextually relevant manner. To address this multifaceted problem, this study developed and implemented an integrated instructional model that embeds NOS concepts within a constructivist learning framework. The model was specifically designed to be implemented within the Rajabhat University context, aiming to enhance the scientific literacy of pre-service teachers and empower them to apply their knowledge effectively

Research Objective

1. To enhance the scientific literacy of general science student teachers at a Rajabhat University using an integrated Nature of Science (NOS) instructional model.

2. To study the opinions of general science student teachers regarding the integrated Nature of Science (NOS) instructional model.

Literature Review

This study is grounded in four interconnected areas of educational theory and research: the Nature of Science (NOS), Scientific Literacy, Constructivist Learning Theory, and Integrated Instructional Models.

Nature of Science (NOS)

Nature of Science (NOS) is a multidisciplinary field that explores the epistemology of science, its methodologies, and its function as a human endeavor situated within cultural contexts (McComas, 2020). It encompasses what science is, how it works, the role of scientists, and the intricate relationship between science, technology, and society. For science education, a functional understanding of NOS is no longer considered a peripheral goal but a central component of scientific literacy (Lederman & Lederman, 2014). An informed view of NOS includes understanding that scientific knowledge is tentative yet durable, empirically based, subjective (theory-laden), a product of human imagination and creativity, and socially and culturally embedded (Abd-El-Khalick, 2012).

International studies have highlighted persistent challenges in developing adequate NOS understanding among pre-service teachers. Akerson and Abd-El-Khalick (2003) conducted a year-long investigation with elementary teachers, revealing that explicit, reflective instructional approaches significantly improved NOS conceptions compared to implicit methods. Similarly, Bell et al. (2011) demonstrated that inquiry-oriented teacher education programs incorporating explicit NOS instruction were more effective than traditional approaches in developing content knowledge and pedagogical understanding.

The Thai Institute for the Promotion of Teaching Science and Technology (IPST, 2018) categorizes NOS understanding into three core components: 1) the Scientific Worldview, which values evidence-based reasoning; 2) Scientific Inquiry, which involves the logical and creative processes of knowledge acquisition; and 3) the Scientific Enterprise, which examines the interplay between science, technology, and society. Research overwhelmingly suggests that an explicit-reflective instructional approach, where NOS concepts are directly addressed and discussed, is more effective in improving learners' NOS views than implicit approaches that assume understanding will emerge simply from doing science (Akerson et al., 2000; Bell et al., 2011). The model in this study aligns with this explicit-reflective principle.

Scientific Literacy

Scientific literacy encompasses multiple dimensions that extend beyond basic scientific knowledge, including understanding of scientific processes, the nature of science, and the ability to apply scientific thinking in real-world contexts (Holbrook & Rannikmae, 2009; Sadler & Zeidler, 2009). The National Research Council (2012) emphasizes that scientifically literate individuals should understand key scientific concepts, appreciate the nature and development of scientific knowledge, and recognize the relationship between science, technology, and society.

Research on pre-service teacher scientific literacy has revealed concerning gaps in various contexts. Al Sultan et al. (2018) found that pre-service elementary teachers demonstrated limited scientific literacy and established relationships between teachers' scientific literacy and self-efficacy in teaching science. Similarly, Murcia and Schibeci (1999) reported that Australian pre-service teachers struggled with understanding the tentative nature of scientific knowledge and the role of creativity in scientific inquiry. In the Thai context, several studies have documented similar challenges. El-Islami and Nuangchalerm (2020) conducted a comparative study of Indonesian and Thai pre-service science teachers, finding that both groups required significant improvement in scientific literacy, with Thai teachers scoring lower in understanding the nature of science. Charoenlikitkawin and Chaikit (2021) examined science student teachers at Thai universities and identified deficiencies across all scientific literacy components, emphasizing the urgent need for curriculum reform.

Thepphitak et al. (2023) studied and identified four key components of scientific literacy among general science teacher students at Rajabhat University, including

1) Scientific Attitude: Individual characteristics that influence behavior and learning in science, including curiosity, scientific awareness, and attitudes toward science.

2) Understanding the Nature of Science (NOS): the ability to interpret, elaborate, and explain the characteristics of science, the pursuit of scientific knowledge, and the science-technology-society relationship.

3) Scientific Inquiry Ability: The skills to apply scientific knowledge and NOS understanding to scientific inquiry and solve problems effectively. It includes utilizing empirical evidence to create scientific explanations, explaining phenomena logically, and solving problems creatively.

4) Application of Science in Context: The ability to transfer scientific knowledge and skills to solve problems and make informed decisions in real-world situations, particularly at the intersection of science, technology, and society.

Effective teacher education curricula must holistically develop these four components to produce scientifically literate educators. This study integrates these four components to develop an instructional model to enhance the scientific literacy of general science student teachers at Rajabhat University.

Constructivist learning theory

Constructivist learning theory, grounded in the works of Piaget and Vygotsky, emphasizes that learners actively construct knowledge through interactions with their environment and social contexts (Driver et al., 1994; Vygotsky, 1978). Constructivism involves three key elements: prior knowledge (schemas), cognitive processes, and new information or experiences. Learners integrate these to achieve understanding through assimilation and accommodation (Chaijaroen, 2011; Ponkul, 2018). In science education, constructivist approaches are effective for developing conceptual understanding and appreciation of NOS (Windschitl, 2002; Zembal-Saul et al., 2002).

Research on constructivist approaches in teacher education has demonstrated positive outcomes for the scientific literacy development of pre-service teachers. Yager and Lutz (1994) found that inquiry-based, constructivist teacher education programs significantly improved pre-service teachers' understanding of science concepts and teaching methods. More recently, Pimpimool (2021) reported that a blended constructivist problem-based learning model was effective for undergraduate students in Thailand, leading to improved critical thinking and problem-solving abilities.

The Integration of constructivist principles with explicit NOS Instruction has shown promise. Akerson and Abd-El-Khalick (2003) demonstrated that explicit-reflective approaches and inquiry-based activities effectively improved pre-service teachers' NOS understanding. Similarly, Bell et al. (2011) found that inquiry-oriented teacher education programs, which explicitly addressed NOS concepts, were more effective than traditional approaches in developing content knowledge and pedagogical understanding.

Integrated Instructional Model

To create holistic learning experiences, educators have increasingly turned to integrated instructional models that combine content knowledge, pedagogical strategies, and a philosophical understanding of science (Park & Oliver, 2008; Shulman, 1987). Recent studies have validated the effectiveness of such models in teacher education. For example, Yuh Anchunda and Kaewurai (2024) developed a social constructivist model that enhanced pre-service teachers' lesson planning abilities through collaborative and reflective practice. Similarly, Theppitak et al. (2524) found that integrating problem-based learning with cognitive coaching significantly improved science student teachers' scientific literacy and critical thinking skills. These studies demonstrate that well-designed, integrated models can simultaneously address multiple facets of teacher development, providing a strong rationale for the approach taken in this research.

Research Conceptual Framework

This study's conceptual framework posits a causal relationship between the instructional intervention and the desired learning outcome. The framework is visualized in Figure 1.

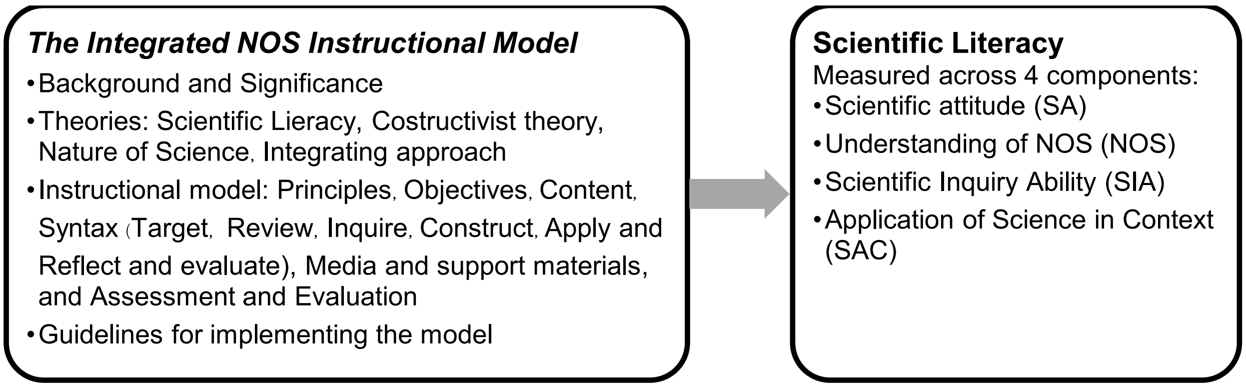

Figure 1 Research Conceptual Framework

The conceptual framework (Figure 1) illustrates the study's core hypothesis. The independent variable is the Integrated NOS Instructional Model, an intervention purposefully designed based on constructivist theory and an explicit approach to teaching NOS. This model is operationalized through a six-step syntax: (1) Target, (2) Review, (3) Inquire, (4) Construct, (5) Apply, and (6) Reflect and Evaluate. The dependent variable is the Scientific Literacy of the general science student teachers. This outcome is not treated as a single entity but as a composite construct comprising the four interrelated components identified by Thepphitak et al. (2523): Scientific Attitude (SA), Understanding of the Nature of Science (NOS), Scientific Inquiry Ability (SIA), and Application of Science in Context (SAC). The framework predicts that engaging students in the six-step instructional process will lead to a measurable and statistically significant enhancement in their overall scientific literacy and its constituent parts.

Research Methodology

Research Design

This research was a quasi-experimental study with a one- group pretest-posttest design to examine the effects of using the integrated NOS instructional model to enhance scientific literacy among general science student teachers at Rajabhat Universities. The Human Research Ethics Committee approved this study under license number COA No. BSRU-REC 660206 on February 28, 2023.

Research Scope

1. Population and samples

The target population comprised 1,689 third-year general science student teachers from 38 Rajabhat Universities across Thailand.

Purposive sampling was employed due to the intensive nature of the intervention, which required close monitoring, and the need for participants from specific geographic and cultural contexts to connect scientific concepts with local wisdom systems in a meaningful way. Sample size determination considered: (1) qualitative intervention components requiring close interaction and observation; (2) available resources for implementation; (3) homogeneous characteristics of the target population; and (4) precedent from similar science education studies using comparable sample sizes (Akerson & Abd-El-Khalick, 2003; Bell et al., 2011). Participant selection criteria included: (1) third-year general science student teacher status; (2) enrollment in the "Science Teaching Using Local Wisdom" course; (3) voluntary commitment to complete the intervention program; and (4) availability for pretest and posttest assessments. The final sample consisted of 21 third-year general science student teachers from Bansomdejchaopraya Rajabhat University, selected based on its representative characteristics of Rajabhat Universities, established science education programs, and administrative support for educational research implementation.

2. Content

2.1 The study focused on the course "Science Teaching using Local Wisdom," which involved examining and analyzing local wisdom, exploring scientific knowledge, and integrating local wisdom into science education.

2.2 Integrated NOS Instructional Model to Enhance Scientific Literacy Among Science Teacher Students. In this study, we developed and implemented an integrated natural science instructional model designed to enhance the scientific literacy of general science student teachers at Rajabhat University. The model includes the following components:

1) Background and Significance: Scientific literacy among science teachers is crucial for fostering students' understanding of the nature of science and their scientific literacy. General science student teachers require robust support to develop these skills for effective classroom practice. The curriculum must contextually integrate nature-of-science concepts to enable student teachers to apply them effectively in practice.

2) Concepts and Theories: The model is based on Scientific Literacy, the Nature of Science concepts, Constructivist Theory, and an Integrated Learning Approach.

3) Instructional Model

3.1) Principles: This program emphasizes scientific literacy through self-directed learning driven by scientific attitudes. Teachers embed nature-of-science concepts to support their application in inquiry and diverse contexts.

3.2) Objectives: Enhance scientific literacy among students in general science education at Rajabhat Universities.

3.3) Content: Science Teaching using local wisdom

3.4) Syntax: Includes six steps: (1) Target-Set goals and pose questions; (2) Review-Evaluate prior knowledge and experiences; (3) Inquire-Conduct scientific inquiries;(4) Construct-Develop scientific explanations; (5) Apply--Use science in real-world contexts; and (6) Reflect and Evaluate-Reflect on learning and assess outcomes.

3.5) Media and Support Materials: Incorporate local wisdom resources, scientific tools, and video content.

3.6) Assessment and Evaluation: This section targets four components of scientific literacy: scientific attitude, understanding of the nature of science, scientific inquiry ability, and application of science in context.

4) Implementation Guidelines: These guidelines address the instructional model, lesson planning and scheduling, the duration of implementation, activities, the roles of learners and teachers, the use of media and learning support materials, and assessment and evaluation.

Preparation of research tools.

The research tools for experimentation and data collection were developed and quality-tested through the following procedures:

1. Integrated Nature of Science Instructional Model: The model comprised four main components: background and significance, concepts and theories, the instructional model structure, and implementation guidelines. Five content experts evaluated the model's appropriateness, providing an overall rating of very high (M = 4.69, SD = 0.50). Individual item scores ranged from 4.20 to 5.00, with standard deviations between 0.00 and 0.80, meeting the established criteria (Srisa-ard, 2010).

2. Integrated NOS Lesson Plans: Three lesson plans were developed, integrating content with local wisdom and relevant theories. Five experts evaluated the appropriateness of these lesson plans, yielding mean scores at the highest level (mean = 4.69, SD = 0.49). The average scores for each item range from 3.80 to 5.00, with standard deviations varying from 0.00 to 0.75; all evaluation items have

an average score greater than 3.50, and standard deviations do not exceed 1, which aligns with the criteria (Srisa-ard, 2010).

3. Scientific Literacy Tests: Develop a scientific literacy test that uses complex items incorporating scenarios and a mix of question formats, including multiple-choice and open-ended questions, to evaluate components of scientific literacy with rubric scoring. Then, the instrument demonstrated high content validity (IOC = 0.80-1.00), appropriate difficulty levels (0.40-0.67), good discrimination (0.27-0.57), and high reliability (α = 0.86).

4. Scientific Attitude Assessment Tool: Develop questions that address the components of scientific attitude, including curiosity, scientific perception and awareness, and attitudes toward science. The assessment tool's Content validity was confirmed (IOC = 0.80-1.00), with good discrimination (0.284-0.567) and high reliability (α = 0.86.

5. Opinion Questionnaire: The questionnaire evaluated student perceptions of the instructional model across four components: content, learning activities, instructional materials/support, and measurement/evaluation. Content validity was established (IOC = 0.80-1.00), with excellent discrimination (0.226-0.921) and very high reliability (α = 0.956).

Data Collection Procedures

1. Orientation Phase: Participants received detailed explanations of the study's purpose, procedures, and expectations. All participants gave informed consent.

2. Pre-test Assessment: Scientific literacy was assessed using all developed instruments. Responses were reviewed for completeness, with follow-up interviews conducted when necessary.

3. Intervention Implementation: The integrated NOS instructional model was implemented through three comprehensive lesson plans over a predetermined schedule, following the six-step syntax (Target, Review, Inquiry, Construct, Apply, and Reflect/Evaluate).

4. Post-test Assessment: Scientific literacy was reassessed using identical instruments and similar procedures to ensure response completeness.

5. Opinion Collection: Participants' opinions regarding the instructional model were gathered and analyzed to assess model acceptability and identify areas for improvement.

Data Analysis

The scores for science attitude (SA), understanding of the nature of science (NOS), science inquiry ability (SIA), and science application in context (SAC) were gathered and calculated as the science literacy score of general science student teachers (SL) using the equation SL = 0.866 (SA) + 0.864 (SIA) + 0.862 (NOS) + 0.814 (SAC) (Theppitak et al., 2023). Statistical analyses included descriptive statistics (means and standard deviations) and inferential statistics (paired-sample t-tests) to compare pre-test and post-test scores and evaluate achievement against the 75% criterion.

Research Results

Scientific Literacy Development

The study examined scientific literacy development across four components before and after implementing the integrated NOS instructional model. Table 1 presents the comparative results.

Table 1 Comparison of Post-test and Post-test Scientific Literacy Scores of General Science Student Teachers Using an Integrated Nature of Science Instruction Model (n = 21)

Component	n	Full score	Pre-test		Post-test		t	p
			Mean	SD	Mean	SD		
SA	21	15	11.45	1.50	12.53	1.40	6.6131*	.000
NOS	21	13	7.26	1.65	9.36	1.32	6.0842*	.000
SIA	21	13	6.64	1.48	9.21	1.79	7.2289*	.000
SAC	21	13	8.05	1.25	9.69	1.59	5.1908*	.000
SL	21	100	61.30	7.27	75.25	6.54	14.4055*	.000

Note: * There is a statistically significant difference (at critical $t_{df=20,\ \alpha=.05}$ = 2.0860, $p < .05$)

1.1 Scientific Attitude (SA): The mean SA score before instruction was 11.45 (SD = 1.50), which increased to 12.53 (SD = 1.40) after instruction. A paired-sample t-test showed a statistically significant improvement in post-test scores compared to pre-test scores at the .05 significance level ($t = 6.6131$, $p < .001$).

1.2 Understanding the Nature of Science (NOS): The mean NOS score before instruction was 7.26 (SD = 1.65), which increased to 9.36 (SD = 1.32) after instruction. A paired-sample t-test showed a statistically significant improvement in post–test scores compared to pre–test scores at the .05 significance level ($t = 6.0842$, $p < .001$).

1.3 Scientific Inquiry Ability (SIA): The mean SIA score was 6.64 (SD = 1.48), increasing to 9.21 (SD = 1.79) after instruction. A paired–sample t–test showed a statistically significant improvement in post–test scores compared to pre–test scores at the .05 significance level ($t = 7.2289$, $p < .001$).

1.4 Application of Science in Context (SAC): The mean SAC score before instruction was 7.80 (SD = 1.46), which increased to 9.36 (SD = 1.91) after instruction. A paired–sample t–test showed a statistically significant improvement in post–test scores compared to pre–test scores at the .05 significance level ($t = 5.1908$, $p < .001$).

1.5 Scientific Literacy (SL): The results obtained when aggregating scores from all components using the scientific literacy relationship equation and converting them into percentages for evaluation are presented here. The sample's mean pre–test scientific literacy score ($n = 21$) was 61.30 (SD = 7.27), which falls within the moderate range. After instruction, the mean score increased to 75.25 (SD = 6.54), reaching a high level. A paired–sample t–test indicated a statistically significant difference between pre– and post–test scores at the .05 significance level ($t = 14.4055$, $p < .001$).

Criterion Achievement Analysis

Post–test scientific literacy scores were compared against the predetermined 75% criterion threshold (Table 2).

Table 2 Comparison of Post–test Scientific Literacy Scores of General Science Student Teachers with the 75% Criterion (Maximum Score = 100, n = 21)

Measure	df	Score		t	p
		Mean	SD		
Criterion (75%)	20	75.00	0.00	0.1741^{ns}	0.4318
Post–test	20	75.25	6.54		

Note: $p < .05$, Critical t–value ($\alpha = .05$, df = 20) = 2.0860; ns = not significant

The post–test scientific literacy scores were compared to a criterion threshold of 75% (out of a maximum score of 100). Table 2 presents the results that the sample ($n = 21$) achieved a post–test mean score of 75.25 (SD = 6.54), which is slightly above the criterion mean of 75.00 (SD = 0.00). However, a t–test revealed no statistically significant difference between the post–test mean and the criterion score at the .05 significance level (t = 0.1741, p = 0.4318), indicating that the post–test performance was statistically comparable to the 75% threshold.

General Science Student Teachers' Opinions on the Integrated NOS Instructional Model

The study assessed the opinions of general science student teachers (n=21) on the integrated NOS instructional model across four components: Content, Learning Activities, Instructional Materials/Support, and Measurement/Evaluation. All components received high overall ratings (mean = 4.32, SD = 0.54). The findings are presented as follows (Table 3)

1. Content (mean = 4.36, SD = 0.50): Students rated the integration of NOS with contextualized lessons highly, particularly noting the engaging nature of content (mean = 4.38), correct integration (4.29), logical sequencing (4.43), and clarity (4.33).

2. Learning Activities (mean = 4.32, SD = 0.50): Activities promoting scientific attitudes (4.33), collaborative knowledge construction (4.48), and evidence–based explanations (4.52) were most valued. Items like fostering creativity scored slightly lower (4.05) but remained above the high threshold.

3 . Instructional Materials/Support (mean= 4.23,SD = 0.68): Resources were deemed appropriate and accessible (4.19), though media alignment with activities (4.10) and equipment provision (4.10) had modestly lower scores.

4. Measurement/Evaluation (mean= 4.23,SD = 0.68): Students appreciated diverse assessment methods (4.33), transparency in scoring (4.43), and inclusion of practical evaluations (4.52).

Table 3 The average level of opinions of general science teacher students towards learning through the integrated NOS instructional model (n=21)

Components	Level of opinions		
	Mean	**SD**	**Level**
1. Content	4.36	0.50	high
1.1 The lesson's content integrates NOS with the contexts and is engaging.	4.38	0.58	high
1.2 The content integrates NOS with the contexts correctly and entirely	4.29	0.45	high
1.3 The content sequence is consistent and appropriate with the context.	4.43	0.49	high
1.4 The integration of NOS with content is straightforward to understand.	4.33	0.47	high
2. Learning activities	4.32	0.50	high
2.1 Promote scientific attitudes	4.33	0.47	high
2.2 Promote learners to understand the scientific worldview correctly.	4.38	0.72	high

Components	Level of opinions		
	Mean	SD	Level
2.3 Promote learners to review experiences to create knowledge together.	4.48	0.50	high
2.4 Promote learners to set goals and their learning plan	4.38	0.49	high
2.5 Promote learners to inquiry by themselves	4.19	0.39	high
2.6 Promote group work and participation	4.19	0.39	high
2.7 Promote learners to think analytically and synthesize	4.33	0.47	high
2.8 Promote learners to think creatively	4.05	0.58	high
2.9 Stimulate learners to have an integrated thinking process	4.24	0.43	high
2.10 Promote learners to explain scientifically using evidence and reason	4.52	0.50	very high
2.11 Provide guidance to learners to create knowledge by themselves using a variety of methods	4.38	0.49	high
2.12 Stimulate learners to have a consistent interest in science and technology	4.33	0.47	high
2.13 Stimulate learners' awareness of science and technology.	4.33	0.47	high
2.14 Promote learners to apply knowledge in their professions and related contexts.	4.24	0.43	high
2.15 Teaching and learning activities are appropriate and consistent with the time.	4.38	0.49	high
3. Instructional materials and support	4.23	0.68	high
3.1 Teaching media are consistent with learning activities	4.10	0.61	high
3.2 Support learning equipment for learners.	4.10	0.81	high
3.3 Learning resources are appropriate and easily accessible	4.19	0.66	high
3.4 Support learners to search for information from reliable research sources, such as online databases, etc.	4.52	0.50	high
4. Measurement and evaluation	4.23	0.68	high
4.1 Measure and evaluate before, during, and after learning	4.19	0.66	high
4.2 Measurement and evaluation methods are diverse	4.33	0.47	high
4.3 Measurement and evaluation cover both theoretical and practical behavior	4.52	0.50	high
4.4 Learners participate in measurement and evaluation	4.38	0.49	high

Components	Level of opinions		
	Mean	SD	Level
4.5 Scoring criteria are transparent and fair	4.43	0.47	high
Average of all aspects	4.32	0.54	high

Discussion

The findings of this study provide robust evidence that the integrated NOS instructional model 032513 is an effective intervention for enhancing the scientific literacy of pre-service science teachers. The statistically significant increase in overall scientific literacy and its constituent components aligns with and extends previous research findings in the field.

Enhancement of Scientific Literacy Through Integrated NOS Instruction.

The significant improvement in scientific literacy scores (from 61.30% to 75.25%) supports the central hypothesis of this research. This result is consistent with the extensive literature advocating for explicit and reflective NOS instruction (Akerson & Abd-El-Khalick, 2003; Lederman & Lederman, 2019). However, the model's success is likely due to its synergistic design, which integrates this explicit approach with constructivist, inquiry-based learning and culturally relevant content (i.e., local wisdom).

The most substantial improvement occurred in scientific inquiry ability, which increased from 6.64 to 9.21 points. This finding supports the effectiveness of the constructivist approach embedded in the model, which emphasized hands-on inquiry experiences and reflective practice. Similar results were reported by Bell et al. (2011), who found that inquiry-oriented teacher education programs significantly improved pre-service teachers' ability to conduct and understand scientific investigations.

The substantial improvement in understanding of the nature of science (from 7.26 to 9.36 points, representing 28.9% growth) addresses a critical gap consistently identified in research on Thai pre-service teachers (Jituafua et al., 2015; Sepkholam & Thiangchantrathip, 2021). This enhancement suggests that the explicit-reflective approach embedded within the model effectively addressed persistent misconceptions about scientific knowledge construction and validation processes. These findings align with international research by Khishfe and Abd-El-Khalick (2002), who demonstrated that explicit, reflective NOS instruction significantly improved students' epistemological understanding compared to implicit approaches.

The improvement in scientific attitude (from 11.45 to 12.53 points) reflects the model's success in fostering positive dispositions toward science learning and teaching. This outcome corroborates research by Akerson et al. (2011), who demonstrated that explicit NOS instruction combined with inquiry-based activities positively influenced pre-service teachers' attitudes toward science and science teaching. The affective dimension improvements are particularly significant, as research consistently demonstrates that teacher attitudes strongly influence instructional effectiveness and student engagement (Özdem et al., 2010).

The enhancement in the application of science in context (from 8.05 to 9.69 points, representing a 20.4% improvement) demonstrates the model's effectiveness in helping students connect scientific knowledge to authentic situations, particularly through the integration of local wisdom. This finding supports research by Aikenhead (2006) and Cobern and Loving (2001), who emphasized the importance of culturally responsive science education in enhancing students' ability to apply scientific concepts meaningfully in diverse contexts.

The overall improvement in scientific literacy, from 61.30% to 75.25% (13.95% enhancement), demonstrates the substantial effectiveness of the integrated approach. This improvement surpasses many reported gains in international intervention studies, suggesting that the synergistic combination of constructivist pedagogy, explicit NOS instruction, and cultural responsiveness creates particularly effective learning conditions. The superior effectiveness demonstrated in this study may be attributed to several factors: (1) the explicit integration of NOS concepts with constructivist learning principles; (2) the incorporation of culturally relevant local wisdom elements; (3) the systematic six-step instructional syntax; and (4) the comprehensive approach addressing all four scientific literacy components simultaneously rather than in isolation.

The model's success in meeting the 75% criterion threshold aligns with high-performing teacher education programs internationally. Research by Hanushek et al. (2019) identified teacher scientific literacy as a critical factor in student achievement, with effective programs typically achieving 70–80% competency levels among graduates.

General Science Student Teachers' Opinions on the Integrated NOS Instructional Model

General science student teachers provided overwhelmingly positive feedback on the integrated NOS instructional model, with an overall mean score of 4.32 (SD = 0.54). Individual item scores ranged from 4.05 to 4.52, all exceeding the 3.50 threshold, with standard deviations below 1.0, indicating consistently positive perceptions and low variability.

The content component received the highest rating (M = 4.36), suggesting students valued the integration of NOS concepts with local wisdom and contextual applications. This supports research on culturally responsive pedagogy emphasizing connections between academic content and students' cultural backgrounds (Gay, 2018; Ladson-Billings, 1995).

Learning activities were also highly rated (M = 4.32), reflecting appreciation for the inquiry-based, collaborative approach. This aligns with research demonstrating positive student responses to active, constructivist learning experiences (Windschitl, 2002; Driver et al., 1994).

The high satisfaction ratings indicate strong acceptance of the model, which is crucial for its sustainable implementation, as teacher acceptance is a key factor in the success of educational innovations (Fullan, 2016; Rogers, 2003). These results demonstrate the model's suitability for enhancing scientific literacy among general science student teachers at Rajabhat Universities.

New Knowledge Gained from the Research

This research contributes new knowledge to the field of science teacher education in several important ways:

1. The primary contribution is the development and validation of an instructional model specifically tailored to the Thai Rajabhat University context. Unlike generic models, this framework integrates NOS concepts with the unique "local wisdom" theme, providing a culturally relevant and practical tool for Thai teacher educators.

2. This study provides robust empirical evidence that a holistic instructional model, one that simultaneously targets attitude, NOS understanding, inquiry skills, and application, can successfully enhance overall scientific literacy. It demonstrates that these components are interconnected and can be effectively developed in an integrated manner rather than in isolation.

3. The research provides insights into how a constructivist model influences the various facets of scientific literacy. The finding that scientific inquiry ability and attitude showed the most significant gains provides valuable information for curriculum designers, suggesting that active, hands-on inquiry is a powerful lever for skill development and affective engagement.

4. The study provides a complete and validated set of resources—including the model's syntax, lesson plans, and assessment tools—that can be adopted or adapted by other institutions facing similar challenges in preparing scientifically literate teachers.

Conclusion

The integrated NOS instructional model proved to be a highly effective intervention, significantly enhancing the scientific literacy of pre-service science teachers and elevating their competency from a moderate to a high level. The model's success is attributable to its synergistic combination of constructivist pedagogy, explicit-reflective NOS instruction, and its contextualization within local knowledge systems, which enabled learners to bridge theory and practice in a meaningful way. The statistically significant improvements across all four components of scientific literacy, coupled with the achievement of the 75% performance criterion and positive student feedback, address a critical gap in Thai science teacher education and offer a robust framework for cultivating scientifically literate educators.

However, this study employed a single-group, purposeful sampling approach to obtain a similar sample, promoting intensive practice and guidance to integrate the nature of science into the context of local wisdom. Each Rajabhat University has a different context and curriculum structure. Future studies should therefore include samples from multiple locations to conduct comparative studies and study the ability to establish definitive causal relationships between the intervention and observed improvements.

Recommendations

Based on the findings, we propose the following recommendations:

1. Recommendations for Implementation

1.1 Given its proven effectiveness and alignment with constructivist learning principles, the integrated NOS instructional model should be widely implemented in science education programs at Rajabhat Universities and similar institutions to promote scientific literacy among student teachers.

1.2 Considering the model’s significant impact on scientific inquiry skills and attitudes, educators should prioritize activities that enhance these areas while supporting growth in understanding NOS and its contextual application.

2. Recommendations for Future Research

2.1 Continuous improvement of the model is recommended, incorporating student feedback and emerging educational research to enhance its adaptability across diverse contexts and learner needs.

2.2 Future research could compare this model with other instructional approaches to identify its relative strengths and possible areas for integration with complementary methods, thereby further optimizing science education outcomes.

2.3 Future research should investigate the long-term retention of enhanced scientific literacy and its application in actual teaching practice through extended follow-up studies that track graduates into their professional careers.

These findings and recommendations underscore the value of the integrated NOS instructional model as a robust framework for developing scientifically literate educators who can foster inquiry-based learning in their future classrooms.

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