

Methods of Cultivating Scientific Thinking in Middle School Physics Experiment Teaching

Ding Fucheng, Amelia Alias, Nurfaradilla Mohamad Nasri

Faculty of Education, Universiti Kebangsaan Malaysia, Bangi, Malaysia

Email: P154385@siswa.ukm.edu.my, amelia.alias@ukm.edu.my, nurfaradilla@ukm.edu.my

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Abstract

Scientific thinking serves as a core component of the core literacy in physics. Currently, experimental instruction in physics in the middle - school is faced with challenges such as excessive attention to operational procedures as such at the expense of thinking progression and more attention to result verification instead of inquiry. This scenario leaves the development of the scientific thought of students as no more than a doctrinaire. Based on constructivist theory, cognitive load theory, and scientific inquiry theory, and with the combination of the actual situation of physics experimental teaching in the middle schools, this paper analytically discusses the cultivation value of scientific thinking of the experimental teaching. It proposes a three - stage development of a path of cognitive activation - inquiry progression - reflective transfer and fabricates specific cultivation techniques based on three dimensions namely; experimental design, teaching implementation, and evaluation feedback. It provides useful guidance to the middle - school physics teachers so that they can maximize the teaching in experimental ways with an ultimate objective of achieving the aim of developing core literacy.

Keywords: Middle School Physics, Experimental Teaching, Scientific Thinking, Cultivation Methods, Practical Reference Guide

Introduction

Research Background and Purpose

In the context of global educational changes aimed at the development of core competencies, scientific literacy of students has become one of the key goals of teaching science. International research (Yao, 2023; Nahar & Machado, 2025) shows a global focus on scientific literacy, with scientific thinking as its core, emphasizing the shift from rote learning to scientific inquiry. In the given context, the scientific thinking, which is considered one of the foundations of physics-specific core competencies, is playing a key role in assisting learners in realizing the principles of physics, exploring natural phenomena, and solving the real-life problems. Being an experiment- based science, middle school physics depends mostly on lab-based teaching in fostering scientific thinking. That practical learning provides not only the gap between abstract theory and concrete practice but it also provides students with genuine experiences of scientific inquiry, fine-tuning of their deductive and inductive logical capacities, and the creative synthesis of coherent mental images of physical phenomena.

China's revised physics curriculum (2022) elevates scientific thinking to a core competency, though the social-institutional dimension of NOS remains underrepresented (21.9%) (Xie et al., 2025). The recent implementation of the revised Chinese high-school physics curriculum policies only serves to highlight this change and the focus on teaching physics as scientific thinking and inquisitive practice as the principle which should underline the further development of students as holistic in their principal areas of competence. Nowadays, Middle school physics experiment teaching involves several issues, including an overemphasis on mechanical tasks, a focus on outcomes rather than exploratory learning, and a lack of cognitive scaffolding. Empirical studies (Remigio et al., 2025; Ma & Lu, 2023; Jin, 2023) confirm these problems, such as scarce open inquiry and uneven experimental resources. Such problems undermine students' motivation to learn independently. This is because integration practical operations with conceptual reasoning is not easy; hence, students find it quite challenging to formulate the habit of scientific thinking. Existing research has gaps: single-dimensional interventions, insufficient solutions to NOS imbalance, lack of evidence for resource balance, and neglect of long-term effects (Xu & Julian, 2025; Carli & Pantano, 2023; Xie et al., 2025). This study re - frames the role of experiments in the process of developing scientific thoughts based on constructivism, the cognitive load theory, and the scientific inquiry model. It suggests practical action plans and special instructional techniques to foster scientific thinking as the key practice in experiment teaching. These proposals seek to address the existing research gaps by drawing on advanced international experience while adapting to China's actual teaching context. They offer both theoretical and practical support for improving experimental teaching in middle school physics and promoting the all-round development of students' core competencies.

Problem Statement

The practical success of promoting scientific thinking in the context of real classroom setting is not very high. The main limitation is due to the constant discrepancies in three related dimensions of the instructional practice:

[1] overinvestment in following steps-by-step instructions discourages meaningful conceptual learning and reasoning based on scientific principles;

[2] laboratory work often favors validation of known results over real, evidence-based discovery-making- therefore inhibiting the internalization of reasoning skills and their generalization to situations;

[3] The absence of developmentally-graded guidance to the development of scientific thinking also serves to suppress natural curiosity of students and limit the externalisation of the reasoning skills towards contextual application. Combined, these inadequacies drastically undercut the pedagogical promise of laboratory-based teaching and, more importantly, worsen the development of mainstream scientific literacy - in particular, physics education.

Research Objectives and Scope

Research Objectives

[1] Investigate the place of practical physics activities in developing scientific thinking in junior high school students, identify the underlying scientific concepts embodied in practical work and define specific, observable signs of scientific thought that one can gain when working on an investigatory, laboratory-based activity.

[2] Work out a cognitively based, three-stage teaching model - consisting of the involvement of prior knowledge, facilitation of open-ended inquiry, and scaffolding reflectivity -

empirically projected and deeply experimented in the practical classroom. [3] Provide pedagogical methods (based on experiment design) that are classroom-ready, with clearly set learning objectives, students act upon performing experimental procedures, and continuous, formative assessment (based on feedback) that serve to systematically enhance the competencies of students on scientific thinking.

[4] Provide science teachers with context-sensitive, practice-based advice on doing physics experiments well- thereby improving the instructional practice and gradually developing abilities of scientific reasoning, problem solving adaptively, and argument construction based on evidence in students.

Research Scope :

[1] Research Focus: The current study is based on the physics laboratory teaching in lower secondary schools, namely, students aged between 13 and 16. It includes experimental work that is grounded in verification and investigative work that involves inquiry tasks, and combined integrative multi-step work, as part of the regular physics course.

[2] Conceptual Framework: The study will rely on major aspects of scientific thinking- i.e., concept model development, logical deduction, justification, inquisitiveness questioning, and innovative problem resolution. The paper highlights how such competencies can be consciously and harmoniously developed through properly organized experimental pedagogy.

[3] Practical Context: The work is intended to be of value to working lower secondary physics teachers, so the practical use of the work has a direct relationship to real-world instructional decision-making, such as the development of lesson plans focused on experiments, facilitating classroom activities, and interpreting data about formative and summative assessment to improve instruction.

Key Research Questions :

[1] How exactly does scientific thinking development in physics laboratory instruction with students look in practice, and what can be done to ensure that such manifestations can be systematically related to the core competencies as established by physics core literacy models?

[2] Basing on constructivist-based principles of learning, cognitive load theory and scientific inquiry models, how can an empirically-based and rigorously designed three-phase developmental trajectory, including the contribution of cognitive engagement, inquiry-based scaffolding, and metacognitive transfer, be built to enhance scientific thought?

[3] Based on three main aspects of instruction, including design of experiments, classroom practice, and formative evaluation, which evidence-based pedagogical methods are the most effective to foster students scientific reasoning, modeling and argument writing?

[4] What ways can the proposed framework of development and the instruction-based strategies embedded in it be in a meaningful way integrated into the specifics and context of real-life physics lab instruction to overcome the end-of-year issues that continue to be faced by the implementation of disproportionate emphasis on procedural performance at the cost of conceptual reasoning, and on the implementation of confirmative experiments, to the detriment of open and genuine investigation?

The Significance of the Research

Theoretical Significance

It has provided a strong theoretical foundation for developing scientific thinking from the perspective of core literacy; it has clearly elucidated the specific pathway for experimental teaching to achieve this goal; and it has effectively bridged the concept of core literacy with subject-specific teaching practice. In the meantime, it generalizes and applies the constructivism theory, cognitive load theory, and scientific inquiry theory to teaching of the physics experiment. This does not only indicate the usefulness of these theories in the process of instilling scientific thinking on students but also expands and enriches connotation of physics education research.

Practical Significance

[1] For educators: This framework will provide a clear roadmap and practical measures to improve experimental teaching so that teachers will cease to rely on the straightforward tactics of scientific thinking formation and will be able to considerably increase the educational value of the laboratory-based education.

[2] For learners: It promotes the intrinsic drive to remain actively engaged in pure science investigations among the learners, aids in the continuous, logical development of vital cognitive skills, such as modeling, deductive thinking, and the analysis of evidence, as well as the development of students to have a sustainable academic background and scientific expertise.

[3] For curriculum advancement: In agreement with the recent additions to the national curriculum such as the focus on developing scientific thinking, it provides concrete, classroom-tested models that inform and fast-track physics curriculum development, thus enhancing the achievement of core competencies in establishment of fundamental physics education.

Literature Review

Curriculum Orientation: The Transmission of Knowledge to Core Literacy Cultivation. Physics at the middle school level as an experimental investigation has undergone radical paradigm shift between traditional knowledge delivery to core literacy development in the global education developments. These scientific thinking, inquiry practice and attitude responsibility are overtly the major literacy outcomes set by China in its Physics Curriculum Standards of Compulsory Education which must be combined with interdisciplinary contexts and real-life situations (Zhang et al., 2021; Luo, 2025; Xie et al., 2025). Guided by the Family Resemblance Approach (FRA) framework, the standards divide the nature of science (NOS) into cognitive-epistemic and social-institutional systems, with cognitive-epistemic elements (scientific practices, methods, knowledge) accounting for 78.1% of NOS representations in the 2022 edition, while social-institutional dimensions (professional activities, social interactions) remain underrepresented (Xie et al., 2025). Internationally, similar trends and diverse practices emerge. Ontario's science curriculum takes scientific thinking as an explicit goal for Grades 1–8, constructing "big ideas" to connect scientific knowledge with life and career skills (Yao, 2023). In Bangladesh, inquiry-based learning (IBL) is introduced as a part of the science curriculum of middle schools to align with the 21st-century skills (Nahar & Machado, 2025), whereas Italy focuses more on scientific practice and student-centered methods to train the skills of experiment and inquiry (Carli & Pantano, 2023). This accord across borders also indicates an international emphasis on the development of scientific

literacy in students in full extent, but there is a dissimilarity in the paths of implementation by area.

Teaching Status and Cognitive Characteristics: Despite ongoing curriculum reforms, long-standing problems persist in middle school physics teaching. Driven by exam pressure, physics classes in China remain largely teacher-centered, emphasizing formula memorization and standardized experimental procedures over independent exploration and creative thinking (Ma & Lu, 2023; Guo & Depaynos, 2023). Most students view physics merely as formula-based problem-solving, lacking interest in its underlying principles; they also rely heavily on teachers, form rigid thinking patterns, and struggle to apply knowledge flexibly (Nugroho & Waslam, 2020; Yao, 2023; Zhang, 2023). Similar issues exist internationally: teacher-dominated instruction limits critical thinking in Bangladesh (Nahar & Machado, 2025), while Italian physics teachers often lack practical experience in inquiry-based teaching (Carli & Pantano, 2023). Additionally, physics is stereotyped as an elite, male-dominated field. Girls in particular associate physics with innate talent and masculinity, which undermines their confidence and participation (Archer et al., 2019).

Core Constraints and International Comparative Insights: The establishment of physics in middle schools is limited by various reasons. In terms of the curriculum, the instructions in traditional textbooks are not comprehensive in terms of experimental orientation, and the study of experiment is not linked with every-day life (Guo & Depaynos, 2023). As a teacher, core teaching conceptions (the understanding of the science and the students, effective teaching) have a direct influence on application of inquiry-based teaching, teachers who perceive science as fixed body of knowledge are less inclined to using student-oriented approach (Lotter et al., 2007). From the system perspective, China's curriculum standards show an imbalance between cognitive-epistemic and social-institutional dimensions of NOS, with social-institutional representation only increasing from 16.0% in 2001 to 21.9% in 2022 (Xie et al., 2025). International comparisons reveal both common tasks and regional differences. Compared with China's standardized curriculum and centralized policy promotion, Ontario's physics education highlights flexibility and practicality, integrating natural sciences, social sciences, and humanities (Yao, 2023). On evaluation, Ontario uses a comprehensive approach that encompasses knowledge understanding, investigative thinking, communication, and application, whereas China continues to emphasize more on knowledge and results of experimental operation (Yao, 2023). Middle school physics education all over the world has to confront the universal challenge of standardizing curriculum at the same time as individualizing it, reconciling the cultures of discipline, and ensuring the equal opportunity of participation.

current situation and existing problem: As a key part of middle school physics, experimental teaching still has many practical shortcomings. Most experiments are verification-based, with fixed steps that leave little room for students to put forward hypotheses or analyze errors (Zhang et al., 2021; Ma & Lu, 2023; Carli & Pantano, 2023). Traditional experiments are often far from real life and focus on ideal situations, which weakens students' internal motivation (Ma & Lu, 2023; Wiwin & Kustijono, 2018). Educational resources are also unevenly distributed: rural and less developed regions lack equipment and spaces, so teachers often use videos or oral explanations instead of hands-on experiments (Ma & Lu, 2023; Jin, 2023; Remigio et al., 2025). Teaching methods are unbalanced too—Remigio et al. (2025) show that

46.97% of teachers use demonstration experiments, while open inquiry only accounts for 3.03%. Besides, digital tools are not widely used. Many teachers lack relevant skills due to outdated knowledge, and high costs of equipment and maintenance further limit the application of digital technology in experiments (Jin, 2023). Finally, the social-institutional dimension is neglected in experimental teaching, with rare involvement of collaboration, peer review, or scientific ethos discussions (Xie et al., 2025).

Reform of Teaching Models: Inquiry-based teaching has become a mainstream reform trend. By setting open experimental topics, teachers guide students to go through the complete inquiry process of "proposing problems → formulating hypotheses → designing experiments → conducting operations → analyzing results," effectively stimulating learning initiative (Zhang et al., 2021). Xu & Julian (2025) developed an inquiry-based experimental manual, and quasi-experimental research showed that students in the experimental group had significantly higher academic performance (average post-test score 71.07 vs. 61.53 in the control group), better learning attitudes, and stronger interest. Nugroho & Waslam (2020) conducted classroom action research on the "center of gravity" topic, finding that experimental activities with challenging questions increased students' enjoyment of learning (from 89% to 94%) and understanding (from 78% to 86%). Problem-solving-oriented experimental styles are more effective in improving student activity and scientific attitude than deductive or technical skill-oriented styles, as they stimulate model-based reasoning (Hadiati et al., 2019). Additionally, "unconventional" physics experiments—using daily necessities such as beverage bottles and cans as tools—rely on their "novelty, uniqueness, and doubt" to bridge the gap between physics teaching and life (Zhao & Sun, 2022).

Diversification of Experimental Forms: Digital technology has diversified physics experiments and boosted teaching effectiveness. Digital information systems (DIS), virtual labs, mobile tools like Phyphox, and Arduino-based setups support real-time data analysis, flexible measurements, and hands-on inquiry, strengthening students' scientific and problem-solving abilities (Jin, 2023; Lv & Peng, 2021; Hadiati et al., 2019; Lestari et al., 2023). Contextual and life-related experiments, such as real-world problem-solving tasks and the RANGKA learning strategy, better connect physics to daily life and improve student learning outcomes (Suryawati & Osman, 2018; Ma & Lu, 2023; Guo & Depaynos, 2023). While combined real-virtual experiments are effective, explicit teaching is still required to deepen students' understanding of the nature of science (Mihret et al., 2023).

Improvement of Teacher Competence and Resource Balance: Teacher competence directly affects experimental teaching effectiveness. Remigio et al. (2025) confirmed a positive correlation between teachers' laboratory knowledge/skill competence and the frequency of experimental teaching implementation—teachers with high competence are more likely to use guided inquiry and open inquiry methods. Professional development models such as learning communities and action research have shown remarkable results: Carli & Pantano (2023) implemented a two-year "Collabora" program, organizing teachers into learning communities, which significantly improved their self-efficacy in experimental teaching and ability to design inquiry-based experiments. Lotter et al. (2007) found that teachers' core teaching conceptions can be adjusted through workshops, laboratory research experiences, and peer feedback. To promote resource balance, digital tools such as virtual laboratories and computer-aided systems have been used to narrow the urban-rural gap (Li et al., 2020;

Carli & Pantano, 2023). Stratified teaching has also been adopted for students of different levels: ordinary classes start with simple experiments and gradually increase difficulty, while experimental classes design application-oriented projects, and experiments are extended to after-class family activities (Guo & Depaynos, 2023).

Methods for Cultivating Scientific Literacy in Middle School Physics Experimental Teaching: Scientific methods are the bridge connecting scientific knowledge and scientific thinking. In experimental teaching, teachers should explicitly infiltrate common methods such as the control variable method, conversion method, and analogy method (Zhang et al., 2021). For example, in the experiment of "exploring the factors affecting the speed of sound propagation," the control variable method is used; in "measuring the electric resistance of a small light bulb," the conversion method reflects resistance through bulb brightness (Zhang et al., 2021). Mathematical tools such as 2D coordinate systems help students visualize abstract logic and summarize physical laws (Zhang et al., 2021). Pham et al. (2022) proposed a six-step scientific inquiry teaching framework that significantly improved students' inquiry competence. Carli & Pantano (2023) integrated control variables and model construction into structured experiments with clear assessment rubrics. Inquiry-based tasks (e.g., pendulum experiments) effectively develop scientific thinking, error analysis, and collaborative skills, supported by digital tools including virtual labs, DIS, and mobile applications (Zhang et al., 2025; Jin, 2023; Lv & Peng, 2021). Guided independent learning also strengthens metacognition and self-directed inquiry (Zimmerman, 2007; Zhang, 2023). A balanced, multi-dimensional evaluation system combining process and outcome assessment is essential, with peer review, portfolios, and AI-enabled feedback enhancing fairness and personalization (Luo, 2025; Kotsis, 2025). Xu & Julian (2025) confirmed that inquiry teaching improves student attitude and interest. Experimental practice strongly promotes scientific attitudes such as curiosity, honesty, and responsibility (Wiwin & Kustijono, 2018). To reduce gender and elite stereotypes, schools should redesign curricula and use innovative experiments (Archer et al., 2019; Zhao & Sun, 2022). Explicit integration of cognitive, epistemic, and social dimensions of the nature of science, along with stories of scientists and social value discussions, helps shape responsible scientific attitudes (Xie et al., 2025; Jin & Song, 2019).

Summary and Prospects

Physical laboratory teaching in the middle schools play a significant role in performing scientific literacy on the learners. Despite the fact that significant advancements in curriculum design have been achieved, the use of educational technologies and the application of the pedagogical strategies, there are several constraints that prevent its full utilization. These are excessive attention to the confirmatory laboratory work, variations in accessibility of teaching facilities in various regions, restricted opportunities of actual scientific inquiry, failure to integrate the nature of science into pedagogic activities.

To mitigate these concerns, the directions of future efforts should focus more on a shift to open-ended, inquiry-based experiments; providing real-world contexts and cross-disciplinary links in lab materials; using digital technology and platforms to address geographical and socioeconomic-based differences; and offering practitioners professional learning more and more grounded in practice to strengthen their competence in technology-enhanced instruction. It is also vital to introduce a complex system of evaluation, which is focused on learning procedures, the principle of constant evaluation, and mastery development, and

active work to prevent gender barriers and elitism towards physics. The curriculum should also be developed to encourage student independence and self learning to create life long scientific interest in the student.

As the rates of educational digitalization increase, the further evolution of the curricular reform, the physics lab education will become the more inclusive, adaptive, and integrative one. By combining evidence-based pedagogy with the new technologies and the overall assessment plans, it would be capable of creating the enduring nature by enhancing the scientific thinking, critical thinking and intellectual curiosity of the students.

Proposed Methodology

Research Strategy

The research follows a unified approach to research that entails integration of both numerical and descriptive research designs. In order to gather information about the process of developing scientific reasoning when working with physics experiments in the schools, the method of data collection is to be applied surveys, direct observations in the classroom, and the open-ended interviews. With the help of constructivist opinions on learning and the model of developing scientific thinking that is developed by Zimmerman, the study examines the opinions that are pronounced by teachers and students, documents the current approaches to teaching, the current problems and also offers the improvement that could be made. In this inquiry, scientific thought is theorized as encompassing five basic skills, which include: the ability to design controlled experiments, the ability to formulate testable hypotheses, the ability to interpret empirical data, the ability to assess sources of error, and the ability to create evidence-based arguments consistent with arguments based on evidence.

Research Population and Sample

In this research 100 middle school students (ages 13 -15 olds) and 12 middle school physics teachers were randomly picked amongst a middle school in Chengdu City, Sichuan Province, China. Random sampling with equal gender distribution was used to select the student sample with representation of both Grade 8 to Grade 9 as the sample is required to represent the students in the various levels of learning. The sample size of the teachers consisted of increased ages of under 30 to more than 50 years of teaching experience, comprising of novice and experienced teachers in order to accommodate a variety of teaching points. Each of the participants was fully aware of the purpose of the study as well as voluntarily enrolling in the study.

Research Instruments

The questionnaires included questions that became more specific on researches conducted by Rosenberg and Hovland (1960) of Affective, Behavioral, and Cognitive (ABC) (Questionnaire designed according to the Affective, Behavioral, and Cognitive (ABC) model). The questions were aimed at gathering information on the attitudes, behaviors, and cognitions of teachers and students about cultivating scientific thinking during physics experiments. All items were evaluated in terms of a 5-point Likert scale (the possibility to agree or disagree) to be sure of being genuine.

Student Questionnaire: It has six elements in close relation, namely, conceptual knowledge of scientific reasoning such as control over variables and interpretation of experimental errors; individual motivation and spontaneous interest in building such reasoning by engaging in physics lab experiments; personal judgment about the effectiveness of instructional practice in teaching them to construct scientific reasoning; applicable application of scientific reasoning strategies in immediately experimental situations; and practical learning to construct controlled experiments and critically interpret empirical findings.

Teacher Questionnaire: consists of six major parts: the knowledge of scientific thinking and its worthiness to be taught, their willingness to use scientific thinking teaching to teach experimental lessons, how frequently teachers engage in teaching through the focus of scientific thinking (such as inquiry-based experiments and problem-driven teaching), whether they can design activities that train scientific thinking, their views of teaching efficacies, and the practical difficulties that they face in the process of teaching scientific thinking.

Classroom Observation: 6 teachers were observed during 30 classes teaching physics experiments, and specific attention was given to four areas: the kind of physics experiments (such as verification-based experiments and inquiry-based experiments), the way in which scientific thinking is developed (such as the explicit instruction of CVS, guided hypothesis, and collaborative data analysis), the ways in which scientific thinking is manifested in the different stages of the experiment (such as asking questions, experimental design, discussion of errors, and making of conclusions), and how students were engaged in activities that require the use of scientific thinking.

Semi-Structured Interviews

To gain in-depth insights into implementation challenges and improvement strategies, semi-structured interviews were conducted with 6 teachers and 6 students, each lasting approximately 10 minutes. The interview outline centered on the following questions:

- (1) What role do you think scientific thinking cultivation plays in middle school physics experiments?
- (2) What difficulties do you encounter in cultivating students' scientific thinking during physics experiments (e.g., student ability gaps, teaching resource limitations)?
- (3) How can we improve the effectiveness of scientific thinking cultivation in middle school physics experiments?

Research Procedures

This experiment was conducted between September 2025 and January 2026 all in three stages. The preparation phase (September) entailed the designing of questionnaires, testing their reliability and validity, finalising of classroom observation checklists and interview outlines, participant selection and informed consent, and preparation of observing and interview schedules with the school. The implementation part (October -December) incorporated the distribution and collection of questionnaires (100 valid student responses, 12 valid teacher responses) which were conducted with the following experiment activities (both group and individual); conducting a 30 classroom observations and conducting individual semi-structured interviews with chosen teachers and students. The statistical processing of the questionnaire data was carried out using SPSS 23 during data analysis phase (January), the organization of the interview transcripts and observation records was done

with the help of content analysis, and triangulation was used to cross-check data of various sources to increase the reliability of the research. To analyze questionnaire data, SPSS 23 with specific descriptive (mean, standard deviation, percentage) and inferential statistics (independent samples t-test, ANOVA) was used to identify effects of such variables as gender of students, grade, and teaching experience of teachers. In the case of observation and interview data, the interview transcripts were word-to-letter transcribed, coded with open coding and thematic analysis to define core themes and observation records summarized to find patterns and differences in the practices of teachers. Findings were cross-verified by triangulation to guarantee the completeness and believability of findings.

Research limitations

Three significant limitations of the research include that, first, the sample used contains the representatives of one middle school, which limits the depth of generalisation of the results; second, the time of the research is rather limited and, hence, it is impossible to determine how the scientific line of reasoning is developed among students in the course of the lesson; and lastly, the factors within the context are not covered completely as these include the availability of laboratory facilities, the professional experience of the teachers, and the organisation of the lesson.

Results

Survey results show that both teachers and students hold generally positive attitudes toward cultivating scientific thinking in middle school physics experiments, but notable differences exist in their cognitive depth and practical willingness.

Among students, 71.2% clearly understood the importance of scientific thinking (e.g., control variable method, error analysis, hypothesis verification) in physics experiments, and 68.5% were highly interested in inquiry-based experiments focusing on scientific thinking training. Over 75% hoped teachers would add more guided activities (e.g., experimental design, data reasoning) to improve their abilities. However, despite strong interest, only 39.4% of students took the initiative to apply scientific thinking to after-class experiments, citing insufficient guidance and difficulty in independent operation as main reasons.

In the case of teachers, 82.3% acknowledged that developing scientific thinking is an objective of teaching physics in middle schools using experimental techniques, and 76.7% of them showed interest in learning new approaches to instruction in the specified area. Besides, 89.1 percent desired professional training to improve their skills in developing inquiry-based experiments and leading the students in logical thinking. Nevertheless, 45.8% also replied that incorporation of systematic thinking development of scientific thinking raises their load in lesson preparation particularly in regards to creating scenarios of inquiry and the standards of assessment which limits their enthusiasm toward practicality in some degree.

Regarding classroom implementation, 62.7% of the students usually engaged in activities related to scientific thinking (e.g., formulating hypothesis, variables analysis, discussing mistakes, etc.) in the classroom. However, they still did not have enough skills to use scientific thought on their own: only 34.6% were able to use the control variable method to plan comparative experiments efficiently, 28.3% of them were weak in data analysis and reasoning of the conclusion. More than two-thirds of students thought that development of scientific

thinking influenced physics positively by increasing the knowledge of principles, enhancing experimental accuracy, and developing the skills to promote problem solving.

Teachers including 85.2% of teachers respondent that they did incorporate cultivation of scientific thinking on the daily teaching and their approaches were relatively single. Namely, 69.4% remained orientated on verification-based experiments, and scientific thinking training was predominantly implicit (i.e. simply mentioning the control variable method without methodological explanation or practice). In the case of the teachers the primary techniques of instruction were demonstrations, group discussions, only 27.8% of the teachers regularly held open inquiry activities, where students were given the chance to design their own experiments. Also, digital tools (e.g. DIS data collection systems) were slight in use, almost 60 percent of still had recourse to traditional experimental tools and manual data recording.

Main Problems in Cultivating Scientific Thinking in Middle School Physics Experiments

Students are aware of the importance of scientific thinking but do not get any systematic training and do not have a chance to practice it independently. The common tendency among teachers has been disjointed insights in the way it can be taught and use little or no coherent, evidence based lesson designs. The systems of assessment and infrastructural development of the experiment are not well-developed, particularly in low-income and rural regions where quite limited lab tools and other digital assets can be found. Stressful loads of work and inequalities in receiving professional assistance also contribute to the inability of teachers to contribute to the development of scientific thinking.

Discussion

Findings show a notable gap between positive attitudes toward scientific thinking cultivation and its actual practice in middle school physics experimental teaching. Although students and teachers understand its significance, for example, students are strongly interested but fully lack the ability to think scientifically independently and this is mostly explained by the fact that they are not trained systematically and do not inquire in the after-class. The majority of educators depend on experiments of a verification type and implicit instruction rather than the structured and inquiry-directed instruction, which is inhibited by excessive workloads, lack of professional training, and the limited availability of digital and experimental resources. The development of the effective scientific thinking is also hampered by the traditional result-oriented evaluation. These findings support the necessity of a structured and stage-by-stage development strategy and specific instructional methods of closing the expectations-vs.-classroom reality gap.

Conclusion

This mixed-methods study based on constructivist learning theory, the cognitive load theory and the principles of scientific inquiry investigates the nature of promoting scientific thinking during the middle school in physics experiments. The results show that there is a regular mismatch between what students learn on the books and what they actually do: whereas students show good conceptual knowledge, they are unable to engage in open-ended inquiry and well-scaffolded instruction cannot be implemented because of real-life problems; time, resources and curricula issues. To fill in this gap, the paper proposes a staged pedagogical model, which includes three their interconnected phases including engaging cognitive interest, scaffolding the inquiry construction, and making the reflective applications in the

teaching process, supported by diversification/context sensitive approaches to teaching. Theoretically, the work further clarifies the development of models of physics-specific core competency development; practically, it can provide effective information to classroom training. Nevertheless, this research has limited scope due to the small sample of participants and a rather short intervention time. Future studies need to endeavor a wider geographic coverage and longitudinal follow-up to measure long-term effects. In addition to this, systemic interventions, which may include: focused teacher professional development, even distribution of teaching materials, and wholesome changes of the curriculum making it possible to measure authentic scientific thinking development and to meet the objectives of physics core literacy are vital in meeting the aim of fulfilling the goal of actualizing the development of authentic scientific thinking and achievement of the objectives of physics core literacy.

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