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METACOGNITIVE SCAFFOLDING AND SELF-QUESTIONING STRATEGIES AS FACTORS IN PRE-SERVICE BASIC SCIENCE TEACHERS' DIGITAL LITERACY AND CRITICAL THINKING SKILLS

Bianca Uzoamaka Mbonu-Adigwe[1], Kazeem Suleiman[2], Mercy Adesola Daramola[3], Stephanie Chiderah Osuji[1], Chioma Blessing Anugwalu[1], Ijeoma Chimeruo Ezeabii[4], Marcel Chuks Ezemoyih[5], Glory Ure Nwankwo[6], Victor Ifeanyichukwu Ukah[7], Chibuzo Maduka Uzoho[8], Matilda Nwakaego Alozie[9], Tunji Henry Ogunyebi[3]

[1]Department of Science Education, University of Nigeria, Nsukka, bianca.mbonuadigwe@unn.edu.ng, https://orcid.org/0000-0002-4873-5204
[2]Department of Science Education, Abubakar Tafawa Balewa University, Bauchi, skazeem@atbu.edu.ng, https://orcid.org/0000-0001-9010-3908
[3]Department of Science Education, Bamidele Olumilua University of Education, Science and Technology, Ikere Ekiti, Ekiti State, daramola.mercy@bouesti.edu.ng
[1] Department of Science Education, University of Nigeria, Nsukka, derahadolphus38@gmail.com, https://orcid.org/0009-0004-9190-3850
[1] Department of Science Education, University of Nigeria, Nsukka, blessingchioma970@gmail.com, https://orcid.org/0009-0004-9267-6792
[4] Department of Business and Entrepreneurship Education, University of Science and Technology, Enugu State, Ijeoma.ezeabii@esut.edu.ng, https://orcid.org/0000-0003-1413-4766
[5] Department of Vocational and Technical Education, Alex Ekwueme Federal University, Ndufu-Alike, Ebonyi State, ezemoyihchuks1961@gmail.com
[6] Department of Integrated Science Education, Federal College of Education (Technical), Umunze, glory.nwankwo@fcetumunze.edu.ng, https://orcid.org/0009-0001-0599-0934
[7] Department of Science Laboratory Technology, Federal College of Agriculture, Ishiagu, Ebonyi State, ukahvictori@fcaishiagu.edu.ng, https://orcid.org/0000-0002-2556-9549
[8] Department of Human Kinetics and Health Education, Alex Ekwueme Federal University, Ndufu-Alike, Ebonyi State, uzoho.chibuzo@funai.edu.ng
[9] Department of Arts and Humanities Education, Alex Ekwueme Federal University, Ndufu Alike, Ebonyi State, marymatildaego@gmail.com, https://orcid.org/0009-0001-2911-0874
[3] Department of Science Education, Bamidele Olumilua University of Education, Science and Technology, Ikere Ekiti, Ekiti State, ogunyebi.tunji@bouesti.edu.ng, https://orcid.org/0000-0002-7378-6679
***Corresponding Author:** Victor Ifeanyichukwu Ukah (ukahvictori@fcaishiagu.edu.ng)

ABSTRACT

This study investigated metacognitive scaffolding and self-questioning strategies as factors in pre-service Basic Science teachers' digital literacy and critical thinking skills in South-East Nigeria. The study adopted a quasi-experimental pretest-posttest non-equivalent group design. The population comprised pre-service Basic Science teachers in teacher education institutions in South-East Nigeria. One hundred and sixty (160) pre-service Basic Science teachers in teacher education institutions in South-East Nigeria were used for the study. The participants were assigned to metacognitive scaffolding and self-questioning strategy groups. Data were collected using Pre-Service Basic Science Teachers' Digital Literacy Test (PBSDLT) and Pre-Service Basic Science Teachers' Critical Thinking Test (PBSCTT). The reliability coefficients of .93 and .91 were obtained for PBSDLT and PBSCTT respectively using Kuder-Richardson 20 (KR-20). The instruments were administered as pretests and posttests, and the data obtained were analysed using means, standard deviations and Analysis of Covariance (ANCOVA) at the 0.05 level of significance. The findings showed that both metacognitive scaffolding and self-questioning strategies improved pre-service Basic Science teachers' digital literacy and critical thinking skills. However, participants exposed to metacognitive scaffolding recorded higher adjusted mean scores than those exposed to self-questioning, and the differences were statistically significant for both digital literacy and critical thinking skills. The findings further revealed that male and female pre-service teachers improved in both outcome variables, although males recorded slightly higher adjusted mean scores. However, the main effects of gender were not statistically significant. Similarly, the interaction effects of instructional strategy and gender on digital literacy and critical thinking skills were not significant. The study concluded that metacognitive scaffolding was more effective than self-questioning in enhancing pre-service Basic Science teachers' digital literacy and critical thinking skills, while its effectiveness was generally consistent across gender. It was recommended that teacher education institutions should integrate metacognitive scaffolding into Basic Science teacher preparation programmes to strengthen prospective teachers' digital competence and higher-order thinking skills.

KEYWORDS: Metacognitive Scaffolding, Self-Questioning, Digital Literacy, Critical Thinking, Pre-Service Basic Science Teachers, Gender.

INTRODUCTION

The contemporary educational environment is increasingly characterized by rapid technological development, expanding access to digital information, and growing demands for learners who can analyse, evaluate and apply information effectively. These changes have altered the competencies expected of teachers, particularly teachers of science who are expected not only to possess sound subject-matter knowledge but also to use digital technologies meaningfully and cultivate higher-order thinking among learners. In teacher education, therefore, digital literacy and critical thinking have become important dimensions of professional preparation. Digital literacy extends beyond the ability to operate computers or access online information; it encompasses the capacity to locate, evaluate, create, communicate and use digital information responsibly for learning and professional purposes. The European Commission's DigCompEdu framework, for example, positions teachers' digital competence around professional engagement, digital resources, teaching and learning, assessment, empowering learners and facilitating learners' digital competence (Redecker, 2017). Similarly, research on pre-service teachers indicates that digital competence involves a combination of technological knowledge, pedagogical application and the ability to integrate digital resources into teaching and learning (Instefjord & Munthe, 2017; Tondeur et al., 2017).

The importance of digital literacy is particularly evident in science education, where digital technologies provide opportunities for accessing scientific information, analysing data, visualising abstract concepts, conducting simulations and communicating scientific explanations. Science teachers increasingly work in learning environments where students encounter information from multiple digital sources and therefore require teachers who can guide them in determining the relevance, credibility and usefulness of such information. Digital literacy consequently has implications not only for teachers' technological proficiency but also for their pedagogical decision-making and capacity to support students' inquiry and problem-solving. Falloon (2020) argues that teacher digital competence should be understood as a multidimensional construct involving both technological and pedagogical capabilities. Evidence from studies of pre-service teachers likewise suggests that ICT self-efficacy, collaboration and institutional support are associated with the development of digital competence, indicating that digital literacy is shaped by more than simple exposure to technology.

For pre-service Basic Science teachers, these competencies are particularly important because Basic Science introduces learners to foundational scientific ideas, processes, inquiry, environmental issues, technology and everyday applications of science. The Nigerian Educational Research and Development Council provides Basic Science and Technology curricula within the national basic education framework, reflecting the position of science as an important component of basic education in Nigeria. The quality of Basic Science instruction is consequently influenced by the preparedness of teachers who will eventually implement the curriculum. Pre-service teachers need to be able to use digital resources to support observation, experimentation, simulation, information search; collaboration and explanation while also helping learners interrogate scientific information rather than merely consume it. Thus, teacher preparation programmes need instructional approaches that develop both the technological and cognitive dimensions of prospective teachers' professional competence.

Closely related to digital literacy is critical thinking, which involves purposeful and reflective processes through which individuals analyse information, evaluate evidence, make reasoned judgments, draw inferences and explain conclusions. Facione (1990) identified interpretation, analysis, evaluation, inference, explanation and self-regulation among the core cognitive skills associated with critical thinking. Ennis (2011) similarly conceptualised critical thinking as reflective and reasonable thinking directed toward deciding what to believe or do. In science education, these abilities are particularly relevant because scientific learning requires learners to interpret evidence, question assumptions, distinguish claims from evidence, solve problems and evaluate explanations. Critical thinking is therefore not an additional skill that can be separated from science learning; it is closely connected with the processes through which scientific knowledge is constructed and evaluated. A substantial review of teacher education research also indicates that the development of critical thinking among student teachers depends on the instructional strategies, assessment practices, feedback and learning environment used during teacher preparation (Lorencová et al., 2019). More recently, a systematic review of 208 studies has confirmed the increasing prominence of critical thinking in teacher education while also identifying substantial variation in how it is conceptualised and developed across contexts (Bubikova-Moan et al., 2026).

Despite the importance of critical thinking, simply exposing pre-service teachers to academic content may not be sufficient to develop the ability to regulate and evaluate their own thinking. Critical thinking requires learners to become conscious of how they approach problems, monitor the adequacy of their reasoning and modify their strategies when necessary. This creates a strong connection between critical thinking and metacognition. Flavell (1979) described metacognition in terms of knowledge about one's cognitive processes and the regulation of those processes. Contemporary research continues to identify metacognition as involving awareness, monitoring and control of cognition, with substantial implications for learning and academic performance (Fleur et al., 2021). When learners are encouraged to plan how they will approach a task, monitor their understanding and evaluate the effectiveness of their strategies, they become more actively involved in regulating their learning rather than relying exclusively on the teacher.

Metacognitive scaffolding provides one possible means of developing this capacity. Scaffolding refers to temporary instructional support that enables learners to perform tasks that they may initially be unable to complete independently. Wood, Bruner, and Ross (1976) introduced the influential scaffolding concept, while subsequent research has emphasised contingency, fading and transfer of responsibility as important features of effective scaffolding. Van de Pol et al. (2010), for instance, identified contingency, fading and transfer of responsibility as central characteristics of scaffolding in teacher–student interaction. Metacognitive scaffolding applies these principles specifically to learners' thinking processes by providing prompts, cues, modelling, reflection opportunities and feedback that help learners plan, monitor and evaluate their learning. Such support is particularly relevant to teacher education because pre-service teachers are themselves developing the capacity to become independent professionals capable of regulating instructional decisions and reflecting on their practice.

The potential value of metacognitive scaffolding for science learning is supported by evidence from Nigerian studies. Samuel et al. (2021), working with secondary school Chemistry students in Anambra State, reported positive relationships between metacognitive awareness and academic achievement, including relationships involving metacognitive knowledge and regulation. Similarly, Ajaja and Agboro-Eravwoke (2017) found differences in metacognitive orientations among science students in Delta State and reported gender differences in some dimensions of metacognitive orientation. In another Nigerian study, Oyovwi and Iroriteraye-Adjekpovu (2021) reported beneficial effects of metacognitive strategy instruction on science students' achievement and retention. More directly related to Anambra State, Uzobuike and Okoli (2021) found that metacognitive teaching was associated with improved achievement and interest among secondary school Physics students. These findings provide a useful basis for investigating whether structured metacognitive scaffolding can produce similar benefits among pre-service teachers, particularly in relation to digital literacy and critical thinking rather than conventional academic achievement alone.

Self-questioning represents another metacognitive strategy that may facilitate the development of higher-order cognitive skills. The strategy requires learners to generate and respond to questions about what they know, what they do not understand, how they arrived at a conclusion, whether available evidence supports a claim and what alternative explanations may exist. Such questioning can make otherwise implicit cognitive processes more explicit and can encourage learners to monitor comprehension and evaluate their reasoning. King (1992) demonstrated the value of guided questioning in promoting higher-order thinking, while Wong's (1985) review of self-questioning research identified metacognitive and active-processing explanations for its effects. A systematic review by Davoudi and Sadeghi (2015) similarly reported that questioning has an important role in facilitating critical thinking, metacognitive skills, subject-matter learning and scaffolding processes. Self-questioning is therefore particularly relevant to Basic Science teacher preparation because prospective teachers need to move beyond recalling scientific facts toward questioning evidence, examining explanations and evaluating the reasoning underlying scientific claims.

The relationship between questioning, metacognition and critical thinking is especially significant in science education. Scientific inquiry involves asking questions, proposing explanations, examining evidence and evaluating conclusions. When pre-service Basic Science teachers are trained to question their own understanding and reasoning, they may become better equipped to model similar cognitive behaviours for their future students. Recent Nigerian evidence provides some support for this proposition. Edom and Mankilik (2024), for example, reported a significant effect of metacognitive questioning techniques on the critical thinking skills of secondary school Physics students in Plateau State. The finding is relevant to the present study because it suggests that questioning processes designed to make learners more conscious of their thinking can contribute to critical-thinking development. However, the participants and outcome examined in that study differ from those proposed in the present research, thereby leaving room to investigate the effects of self-questioning among pre-service Basic Science teachers.

The connection between metacognitive strategies and digital literacy is also increasingly important because digital environments require learners to regulate how they search for, select, evaluate and use information. Digital information is abundant, but accessibility does not necessarily guarantee accuracy, relevance or credibility. A digitally literate teacher must therefore be capable of asking questions such as: What information do I need? Where should I search for it? Is the source credible? What evidence supports the information? How does it relate to the problem under investigation? What alternative interpretations are possible? These are simultaneously digital-literacy and metacognitive questions. Recent research on digital technology and self-regulated learning indicates that digital tools can support metacognition through feedback, dashboards and other forms of scaffolding when these technologies are deliberately integrated into instruction. Thus, metacognitive scaffolding and self-questioning may provide cognitive processes through which pre-service teachers learn not merely to use digital technologies but to use them critically and purposefully.

The need for such instructional approaches is reinforced by developments in teacher education. Teacher education programmes are expected to prepare prospective teachers for classrooms characterised by digital resources, learner-centred pedagogy, collaborative learning and higher-order thinking. However, possessing access to technology does not automatically translate into pedagogically meaningful digital competence. Research on pre-service teachers has

shown that digital competence is associated with factors such as self-efficacy, collaboration and institutional support (Haşlaman et al., 2023; Tondeur et al., 2017). This suggests that teacher preparation should deliberately create learning experiences through which pre-service teachers can practise technology use while simultaneously reflecting on the purposes, consequences and quality of their decisions.

In Nigeria, the issue has particular relevance because teacher education institutions operate within an educational environment in which digital transformation is increasingly influencing teaching, learning and assessment. Recent Nigerian research on science and technology education students and lecturers has examined attitudes toward metacognitive strategies in Colleges of Education, suggesting that metacognitive approaches are relevant within teacher-preparation contexts (Adamu et al., 2022). At the same time, recent work involving Nigerian pre-service teachers has highlighted the continuing need to strengthen digital competencies and prepare prospective teachers for technology-rich classrooms. For example, Abdulganiyu et al. (2026) reported on a technology-driven intervention for pre-service teachers and identified digital literacy, instructional planning, collaborative learning and technology integration as important areas of teacher preparation. These developments underscore the importance of examining instructional strategies that can simultaneously strengthen prospective teachers' digital competence and higher-order thinking irrespective of gender.

Gender is another variable that warrants consideration in examining the effects of metacognitive scaffolding and self-questioning strategies. Gender should not automatically be assumed to determine learning outcomes; rather, it can be investigated to establish whether male and female pre-service teachers respond differently to the instructional strategies. Existing evidence on gender and metacognitive engagement is not entirely uniform. For example, Ajaja and Agboro-Eravwoke (2017) reported gender differences in selected dimensions of science students' metacognitive orientations, whereas recent research among Nigerian undergraduates found higher female use of some metacognitive reading strategies but no significant difference in another dimension (Anyanwu, 2026). These differences indicate that gender may be worth examining empirically rather than assuming either the presence or absence of a gender effect.

The question of gender moderation is particularly important because the effect of an instructional strategy can depend on the characteristics of the learners and the learning environment. Research on critical-thinking interventions in teacher education has identified learner characteristics, instructional methods, feedback and contextual conditions as factors that can influence intervention outcomes (Lorencová et al., 2019). However, examining gender as a moderator can provide evidence on whether the effects of metacognitive scaffolding and self-questioning on digital literacy and critical thinking are consistent across male and female pre-service Basic Science teachers. Such evidence may help teacher educators determine whether the strategies can be implemented broadly or whether particular learner groups require additional instructional support.

Although existing studies have established relationships between metacognition and learning, questioning and higher-order thinking, and digital competence and teacher preparation, an important research gap remains. Much of the available evidence has focused on secondary school students, academic achievement, reading comprehension or individual dimensions of metacognition. Relatively fewer studies have simultaneously examined metacognitive scaffolding and self-questioning as instructional interventions for developing both digital literacy and critical thinking among pre-service Basic Science teachers. The gap is even more evident when gender is considered as a moderating variable within the Nigerian teacher-education system. Recent systematic reviews continue to call attention to the diversity of approaches used to develop critical thinking in teacher education and the need for further research into effective instructional interventions. It is against this background that the present study investigates metacognitive scaffolding and self-questioning strategies as factors in pre-service Basic Science teachers' digital literacy and critical thinking skills in South-East, Nigeria, with gender examined as a moderating variable. By focusing on pre-service Basic Science teachers, the study shifts attention from students who are merely recipients of instruction to prospective teachers who will themselves become facilitators of scientific learning.

Purpose of the Study

The main purpose of the study is to determine the effects of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' digital literacy and critical thinking skills in South-East, Nigeria. Specifically, the study sought to determine the:

1. effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' digital literacy skills;
2. influence of gender on pre-service Basic Science teachers' digital literacy skills;
3. interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills;
4. effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' critical thinking skills;
5. influence of gender on pre-service Basic Science teachers' critical thinking skills;
6. interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills.

Research Questions

The following research questions guided the study:

1. What is the effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' digital literacy skills?
2. What is the influence of gender on pre-service Basic Science teachers' digital literacy skills?
3. What is the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills?
4. What is the effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' critical thinking skills?
5. What is the influence of gender on pre-service Basic Science teachers' critical thinking skills?
6. What is the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills?

Hypotheses

The following null hypotheses were formulated and tested at the 0.05 level of significance;

H_{01}: There is no significant difference in the mean digital literacy skills rating scores of pre-service Basic Science teachers taught using metacognitive scaffolding strategy and those taught using self-questioning strategy.

H_{02}: There is no significant difference in the mean digital literacy skills rating scores of male and female pre-service Basic Science teachers.

H_{03}: There is no significant interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills.

H_{04}: There is no significant difference in the mean critical thinking skills rating scores of pre-service Basic Science teachers taught using metacognitive scaffolding strategy and those taught using self-questioning strategy.

H_{05}: There is no significant difference in the mean critical thinking skills rating scores of male and female pre-service Basic Science teachers.

H_{06}: There is no significant interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills.

METHODS AND MATERIALS

The study adopted a quasi-experimental research design, specifically the pretest-posttest non-equivalent group design. According to Nworgu (2015), quasi-experimental design is an experimental design in which random assignment of subjects to experimental and control groups is not possible, and therefore intact or pre-existing groups are used. The design permits the researcher to manipulate the independent variable and observe its effect on the dependent variables without randomly assigning individual participants to the treatment groups. The pretest-posttest non-equivalent group design was considered appropriate for the present study because the pre-service Basic Science teachers were selected from existing classes, making individual random assignment impracticable. Reorganising the participants into newly constituted classes could disrupt the normal academic programme of the institutions. Thus, intact classes were retained and assigned to the two treatment conditions. The pretest scores served as baseline measures and were used as covariates during data analysis to statistically control for possible initial differences between the groups. The study was conducted in South-East, Nigeria. The area comprised five states, namely; Abia, Anambra, Ebonyi, Enugu and Imo. The area has a strong tradition of formal education, with universities, colleges of education and other teacher-training institutions that prepare teachers for different levels of the Nigerian education system. The population of the study comprised all the year 2 pre-service Basic Science teachers enrolled in relevant teacher education programmes in Colleges of Education and universities (both state and federal) in South-East, Nigeria in 2024/2025 academic session. A sample size of 160 pre-service Basic Science teachers was used for the study. Simple random sampling technique was used to sample two states out of the five states in South-East, Nigeria. Pre-service Basic Science teachers in Colleges of Education and universities in the two states (Anambra and Enugu States) constitute the sample size for the study.

Instruments for Data Collection

Two major instruments were used for data collection. They were: Pre-Service Basic Science Teachers' Digital Literacy Test (PBSDLT) and Pre-Service Basic Science Teachers' Critical Thinking Test (PBSCTT). The Pre-Service Basic Science Teachers' Digital Literacy Test (PBSDLT) was developed by the researchers to measure the digital literacy skills of the participants. The instrument was divided into two sections, A and B. section A sought information on the demographic information of the respondents such as school name, registration number and gender. Section B of the instrument covered major dimensions of digital literacy relevant to prospective Basic Science teachers. These included access and use of digital information, digital communication and collaboration, evaluation of digital information, digital content creation and responsible and safe use of digital technologies. The participants received one mark for each correct response and zero for an incorrect response. The total score represented the participant's level of digital literacy.

The Pre-Service Basic Science Teachers' Critical Thinking Test (PBSCTT) was developed by the researchers to measure the participants' critical thinking skills. The test focused on skills such as analysis, interpretation, evaluation, inference, explanation and reasoning. Items were constructed around Basic Science-related situations requiring participants to examine information, evaluate evidence, identify relationships, draw conclusions and justify decisions. The participants received one mark for each correct response and zero for an incorrect response. Higher scores indicated a higher level of demonstrated critical thinking skills.

Two treatment packages were developed for the study: the Metacognitive Scaffolding Instructional Package (MSIP) and the Self-Questioning Instructional Package (SQIP). The Metacognitive Scaffolding Instructional Package was designed to guide participants through the processes of planning, monitoring and evaluating their learning. During instruction, the researcher provided structured prompts and cues to help participants become conscious of their thinking processes. The treatment followed three major stages:

1. Planning: Participants were guided to identify the learning task, activate prior knowledge, establish learning goals and determine appropriate strategies for approaching the task.
2. Monitoring: Participants were encouraged to monitor their understanding while learning, identify areas of difficulty, check their reasoning and determine whether their learning strategies were effective.
3. Evaluation: Participants reflected on what they had learned, evaluated the strategies they had used, identified errors or misconceptions and considered how they could improve their approach to similar tasks. The scaffolds were gradually reduced as participants demonstrated increased ability to regulate their own learning.

The Self-Questioning Instructional Package was designed to encourage participants to generate and answer questions before, during and after learning activities. The strategy involved teaching participants to use questions to examine their understanding, reasoning and conclusions. Before learning activities, participants were guided to ask questions such as: What do I already know about this topic? What do I need to find out? What do I expect to learn? During learning activities, participants were encouraged to ask: Do I understand this information? What evidence supports this explanation? Why does this happen? Is there another possible explanation? How can I verify this information? After learning activities, participants were guided to ask: What have I learned? What evidence supports my conclusion? What did I find difficult? What mistakes did I make? How could I solve a similar problem differently? The repeated use of such questions was intended to encourage participants to become active monitors and evaluators of their own learning.

The instruments and treatment packages were subjected to face validation by two experts in Science Education (Integrated Science Education unit and Measurement and Evaluation unit) and one from Computer and Robotic Education, Faculty of Vocational and Teacher Education, University of Nigeria, Nsukka. The experts were asked to examine the instruments in terms of the relevance of the items to the study objectives, clarity of language, adequacy of coverage, appropriateness of the response format and suitability for pre-service Basic Science teachers. The experts' observations and suggestions were used to modify ambiguous, irrelevant or poorly structured items before the instruments were subjected to reliability testing. A table of specifications was developed for the critical thinking test to ensure adequate representation of the content areas and cognitive processes intended to be measured. The digital literacy test was similarly developed based on the dimensions of digital literacy covered by the study. This was done to establish the content validity of the instruments.

The reliability of the instruments was established through a pilot test involving pre-service Basic Science teachers from University of Nigeria, Nsukka who were not part of the main study, but shares characteristics similar to those of the institutions involved in the main study. The reliability of the digital literacy test and critical thinking test were determined using Kuder-Richardson 20 (KR-20) since the items of the instrument were scored dichotomously. The reliability coefficients of .93 and .91 were obtained respectively. The instruments were considered suitable for the main study after demonstrating acceptable reliability coefficients.

Experimental Procedure

The experiment was conducted in three major phases: pre-treatment, treatment and post-treatment phases. Before the commencement of the experiment, permission was obtained from the participating institutions. The participants were informed about the purpose and general procedures of the study. The researcher also trained the research assistants who participated in the administration of the instruments and implementation of the treatment. The PBSDLT and PBSCTT were administered to the participants as pretests. The purpose of the pretest was to establish the participants' baseline levels of digital literacy and critical thinking skills before exposure to the experimental treatments.

Following the pretest, the two experimental groups received instruction using their respective strategies. The metacognitive scaffolding group was taught using structured metacognitive prompts, modelling, monitoring cues, reflection activities and gradual withdrawal of instructional support. The self-questioning group was taught using systematic questioning before, during and after learning activities.

The intervention lasted for a period of four weeks, with the same Basic Science content, instructional objectives, learning duration and learning resources provided to both groups. The major difference between the groups was the instructional strategy employed. To minimise treatment contamination, the two groups were taught separately.

Research assistants were also instructed to adhere strictly to the treatment procedures specified in the instructional packages.

At the completion of the intervention, the PBSDLT and PBSCTT were administered again to the participants as posttests. The posttest scores were used to determine changes in digital literacy and critical thinking skills following exposure to the instructional strategies. The same testing conditions were maintained as much as possible for both groups. The researcher ensured that the administration of the instruments was conducted under standardised conditions.

Control of Extraneous Variables

Several measures were adopted to control extraneous variables that could affect the findings of the study.

Teacher effect: The same researcher or trained research assistants were used to implement the treatments in accordance with the instructional packages. This helped to minimise differences attributable to teacher characteristics.

Instructional content: Both experimental groups were exposed to the same Basic Science content and learning objectives. Only the instructional strategy differed.

Instructional time: The groups were allocated approximately the same amount of instructional time.

Testing effect: The pretest and posttest administrations were conducted under similar conditions, while appropriate procedures were used to minimize the possibility of participants obtaining undue advantage from prior exposure to the test.

Instruction between groups: The experimental groups were taught separately to minimise communication about the treatment procedures.

Researcher bias: Treatment guides and structured lesson plans were developed before the intervention. Research assistants were trained to follow the procedures consistently.

Method of Data Analysis

The data collected were analysed using descriptive and inferential statistics. Mean and standard deviation were used to answer the research questions. Analysis of Covariance (ANCOVA) was used to test the hypotheses because the study employed a pretest-posttest quasi-experimental design. The pretest scores served as covariates, while the posttest scores constituted the dependent measures. The hypotheses were tested at the 0.05 level of significance. Where the probability value was less than 0.05, the corresponding null hypothesis was rejected; where the probability value was greater than or equal to 0.05, the null hypothesis was not rejected.

RESULTS

Research Question One: What is the effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' digital literacy skills?

Table 1: Mean analysis of the effects of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' digital literacy skills

		Pre-test		Post-test		Adjusted Mean
Treatment	N	Mean	Std. Dev.	Mean	Std. Dev.	
Metacognitive Scaffolding	79	46.77	7.74	73.23	7.36	73.47
Self-Questioning	81	46.20	6.30	64.71	6.99	64.73

Result in Table 1 shows that the pre-service Basic Science teachers exposed to metacognitive scaffolding had a pre-test digital literacy score of 46.77 (SD = 7.74), which increased to 73.23 (SD = 7.36) at post-test. The adjusted post-test mean was 73.47. This indicates a substantial improvement in digital literacy skills following exposure to the metacognitive scaffolding strategy. For the self-questioning group, the pre-service teachers had a pre-test mean score of 46.20 (SD = 6.30), which increased to 64.71 (SD = 6.99) at post-test, with an adjusted mean of 64.73. This also indicates an improvement in digital literacy skills following exposure to the self-questioning strategy. A comparison of the adjusted means shows that the metacognitive scaffolding group obtained a higher adjusted mean score (73.47) than the self-questioning group (64.73). Thus, descriptively, pre-service Basic Science teachers exposed to metacognitive scaffolding demonstrated greater improvement in digital literacy skills than those exposed to self-questioning.

Research Question Two: What is the influence of gender on pre-service Basic Science teachers' digital literacy skills?

Table 2: Mean and standard deviation of the influence of gender on pre-service Basic Science teachers' digital literacy skills

		Pre-test		Post-test		Adjusted mean
Gender	N	Mean	Std. Deviation	Mean	Std. Deviation	
Male	62	46.79	6.92	68.65	7.93	69.76
Female	98	46.28	7.12	69.09	8.61	68.45

Result in Table 2 presents the mean and standard deviation of pre-service Basic Science teachers' digital literacy skills based on gender. The results show that the male pre-service teachers had a pre-test mean score of 46.79 (SD = 6.92), which increased to a post-test mean score of 68.65 (SD = 7.93). Their adjusted mean score was 69.76. This indicates an improvement in the digital literacy skills of the male pre-service teachers following the intervention. Similarly, the female pre-service teachers had a pre-test mean score of 46.28 (SD = 7.12), which increased to a post-test mean score of 69.09 (SD = 8.61). Their adjusted mean score was 68.45, also indicating an improvement in digital literacy skills following the intervention. Comparatively, the male pre-service teachers had a higher adjusted mean score of 69.76 than the female pre-service teachers, who had an adjusted mean score of 68.45. The difference in adjusted means is 1.31 points, indicating that the male participants had a slightly higher adjusted digital literacy score than the female participants.

Research Question Three: What is the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills?

Table 3: Mean analysis of the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills

			Pre-test		Post-test	
Treatment	Gender	N	Mean	Std. Dev.	Mean	Std. Dev.
Metacognitive Scaffolding	Male	23	47.87	7.84	73.96	5.09
	Female	56	46.32	7.73	72.93	8.14
Self-Questioning	Male	39	46.15	6.34	65.51	7.67
	Female	42	46.24	6.33	63.98	6.30

Result in Table 3 presents the mean analysis of the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills. The results indicate that male pre-service teachers exposed to metacognitive scaffolding had a pre-test mean score of 47.87 (SD = 7.84), which increased to a post-test mean score of 73.96 (SD = 5.09). Female pre-service teachers exposed to the same strategy had a pre-test mean score of 46.32 (SD = 7.73), which increased to a post-test mean score of 72.73 (SD = 8.14). Thus, both male and female pre-service teachers exposed to metacognitive scaffolding showed considerable improvement in their digital literacy skills, with the male participants recording a slightly higher post-test mean. For the self-questioning strategy, male pre-service teachers had a pre-test mean score of 46.15 (SD = 6.34), which increased to a post-test mean score of 65.51 (SD = 7.67). Female pre-service teachers had a pre-test mean score of 46.24 (SD = 6.33), which increased to a post-test mean score of 63.98 (SD = 6.30). This also indicates an improvement in digital literacy skills for both male and female participants exposed to the self-questioning strategy, although the male participants recorded a higher post-test mean. Comparing the two instructional strategies across gender, male pre-service teachers exposed to metacognitive scaffolding obtained the highest post-test mean score of 73.96, followed by female pre-service teachers exposed to metacognitive scaffolding with a mean of 72.73. Male participants exposed to self-questioning recorded a mean of 65.51, while female participants exposed to self-questioning recorded the lowest mean of 63.98. The pattern suggests that metacognitive scaffolding was associated with higher digital literacy scores for both male and female pre-service teachers compared with self-questioning. It also suggests that male participants had slightly higher post-test scores than female participants within each instructional strategy.

Research Question Four: What is the effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' critical thinking skills?

Table 4: Mean analysis of the effects of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' critical thinking skills

		Pre-test		Post-test		Adjusted Mean
Treatment	N	Mean	Std. Dev.	Mean	Std. Dev.	

Metacognitive Scaffolding	79	54.15	4.42	74.56	5.40	74.89
Self-Questioning	81	54.88	9.56	67.64	9.10	67.64

Result in Table 4 presents the mean analysis of the effects of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' critical thinking skills. The results show that the 79 pre-service teachers exposed to metacognitive scaffolding had a pre-test mean score of 54.15 (SD = 4.42), which increased to a post-test mean score of 74.56 (SD = 5.40). The adjusted mean score of 74.89 indicates that the improvement in critical thinking skills remained evident after adjusting for the participants' initial pre-test scores. Similarly, the 81 pre-service teachers exposed to the self-questioning strategy had a pre-test mean score of 54.88 (SD = 9.56), which increased to a post-test mean score of 67.64 (SD = 9.10). The adjusted mean score was also 67.64, indicating an improvement in critical thinking skills following exposure to the self-questioning strategy. Comparatively, the metacognitive scaffolding group recorded a higher adjusted mean score of 74.89 than the self-questioning group, which recorded an adjusted mean of 67.64. The difference of 7.25 mean points suggests that pre-service Basic Science teachers exposed to metacognitive scaffolding demonstrated greater improvement in critical thinking skills than those exposed to self-questioning. Thus, based on the descriptive mean analysis, metacognitive scaffolding appeared to have a stronger effect on the development of pre-service Basic Science teachers' critical thinking skills.

Research Question Five: What is the influence of gender on pre-service Basic Science teachers' critical thinking skills?

Table 5: Mean and standard deviation of the influence of gender on pre-service Basic Science teachers' critical thinking skills

		Pre-test		Post-test		Adjusted mean
Gender	N	Mean	Std. Deviation	Mean	Std. Deviation	
Male	62	54.47	8.03	71.08	8.39	72.01
Female	98	54.55	7.13	71.04	8.20	70.52

Result in Table 5 presents the mean and standard deviation of the influence of gender on pre-service Basic Science teachers' critical thinking skills. The results show that the male pre-service teachers had a pre-test mean score of 54.47 (SD = 8.03), which increased to a post-test mean score of 71.08 (SD = 8.39). Their adjusted mean score was 72.01, indicating an improvement in critical thinking skills following the instructional intervention. Similarly, the female pre-service teachers had a pre-test mean score of 54.55 (SD = 7.13), which increased to a post-test mean score of 71.04 (SD = 8.20). Their adjusted mean score was 70.52, also indicating an improvement in critical thinking skills following the intervention. Comparatively, the male pre-service teachers recorded a slightly higher adjusted mean score of 72.01 than the female pre-service teachers, who recorded an adjusted mean of 70.52. The difference of 1.49 mean points indicates that the male participants had a slightly higher adjusted critical thinking score than their female counterparts.

Research Question Six: What is the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills?

Table 6: Mean analysis of the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills

			Pre-test		Post-test	
Treatment	Gender	N	Mean	Std. Dev.	Mean	Std. Dev.
Metacognitive Scaffolding	Male	23	54.04	4.82	75.57	4.93
	Female	56	54.20	4.30	74.14	5.58
Self-Questioning	Male	39	54.72	9.48	68.44	8.92
	Female	42	55.02	9.75	66.90	9.31

Result in Table 6 presents the mean analysis of the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills. The results show that male pre-service teachers exposed to metacognitive scaffolding had a pre-test mean score of 54.04 (SD = 4.82), which increased to a post-test mean score of 75.57 (SD = 4.93). Female pre-service teachers exposed to metacognitive scaffolding had a pre-test mean score of 54.20 (SD = 4.30), which increased to a post-test mean score of 74.14 (SD = 5.58). This indicates that both male and female pre-service teachers exposed to metacognitive scaffolding improved considerably in their critical thinking skills, with the male participants recording a slightly higher post-test mean. For the self-questioning strategy, male pre-service teachers had a pre-test mean score of 54.72 (SD = 9.48), which increased to a post-test mean score of

68.44 (SD = 8.92). Female pre-service teachers recorded a pre-test mean score of 55.02 (SD = 9.75), which increased to a post-test mean score of 66.90 (SD = 9.31). Thus, both male and female participants exposed to self-questioning also demonstrated improvement in critical thinking skills, although the male participants had a higher post-test mean than the female participants. A comparison across the instructional strategies shows that male participants exposed to metacognitive scaffolding recorded the highest post-test mean of 75.57, followed by female participants exposed to metacognitive scaffolding with a mean of 74.14. Male participants exposed to self-questioning recorded a post-test mean of 68.44, while female participants exposed to self-questioning recorded the lowest post-test mean of 66.90. The pattern therefore indicates that metacognitive scaffolding was associated with higher critical thinking scores for both male and female pre-service teachers than self-questioning. Within each instructional strategy, male participants also recorded slightly higher post-test means than female participants.

H_{01}: There is no significant difference in the mean digital literacy skills rating scores of pre-service Basic Science teachers taught using metacognitive scaffolding strategy and those taught using self-questioning strategy.

Table 7: Summary of Analysis of covariance (ANCOVA) of significant difference in mean digital literacy skills rating scores of pre-service Basic Science teachers taught using metacognitive scaffolding strategy and those taught using self-questioning strategy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2973.754[a]	4	743.439	14.293	.000	.269
Intercept	17576.438	1	17576.438	337.917	.000	.686
PrePBSDLT	11.201	1	11.201	.215	.643	.001
Treatment	2742.786	1	2742.786	52.732	.000	.254
Gender	61.809	1	61.809	1.188	.277	.008
Treatment * Gender	1.797	1	1.797	.035	.853	.000
Error	8062.190	155	52.014			
Total	771003.000	160				
Corrected Total	11035.944	159				

Result in Table 7 presents the summary of the analysis of covariance (ANCOVA) conducted to determine whether there was a significant difference in the mean digital literacy skills rating scores of pre-service Basic Science teachers taught using metacognitive scaffolding and those taught using self-questioning strategy, after controlling for their pre-test scores. The main effect of treatment was significant, $F(1, 155) = 52.732$, $p < .05$, partial $\eta^2 = .254$. This indicates that there was a significant difference in the digital literacy skills of pre-service Basic Science teachers taught using metacognitive scaffolding and those taught using self-questioning strategy, after controlling for the pre-test scores. The partial eta squared of .254 indicates that approximately 25.4% of the variance in the adjusted digital literacy skills scores was associated with the treatment factor.

H_{02}: There is no significant difference in the mean digital literacy skills rating scores of male and female pre-service Basic Science teachers.

Result in Table 7 was also used to test hypothesis two. The main effect of gender was not significant, $F(1, 155) = 1.188$, $p = .277$, partial $\eta^2 = .008$. This indicates that there was no significant difference in the digital literacy skills of male and female pre-service Basic Science teachers after controlling for the pre-test scores and treatment. The effect size was also small, accounting for approximately 0.8% of the variance in the outcome.

H_{03}: There is no significant interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills.

Result in Table 7 was used to test hypothesis three. The interaction effect between treatments and gender was not significant, $F(1, 155) = 0.035$, $p = .853$, partial $\eta^2 < .05$. This indicates that the effect of instructional strategy on pre-service Basic Science teachers' digital literacy skills did not significantly differ according to gender. In other words, the effectiveness of metacognitive scaffolding relative to self-questioning was not significantly dependent on whether the pre-service teacher was male or female. The non-significant interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills was also explained using the profile plot in fig.1 below.

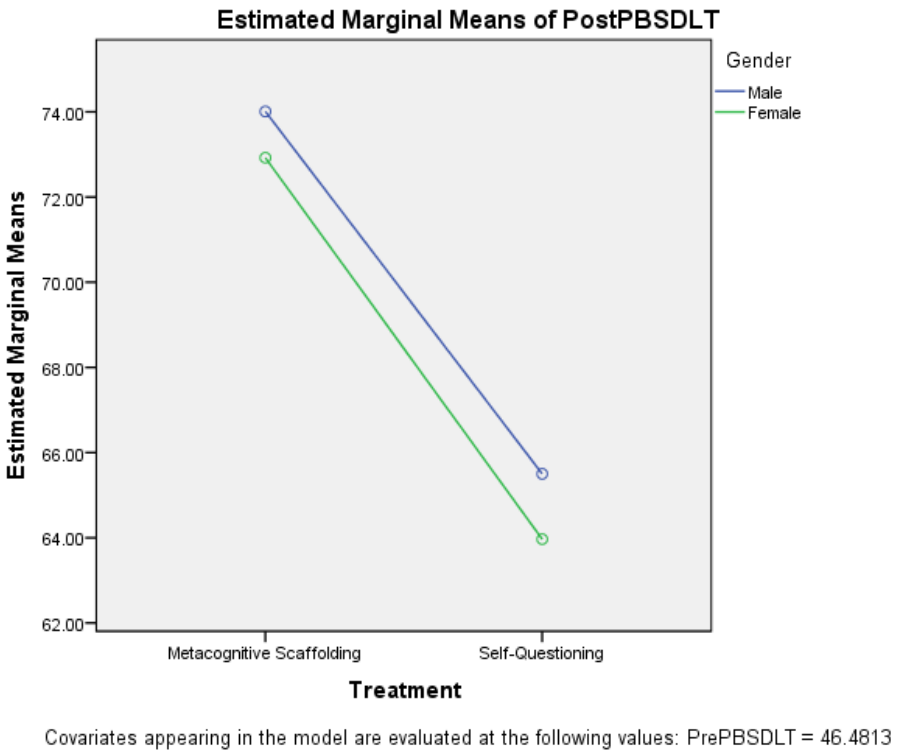

Fig 1: Graph of the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills

The profile plot shows that both male and female pre-service Basic Science teachers had higher estimated marginal mean scores in digital literacy skills when taught using metacognitive scaffolding than when taught using self-questioning. Male participants recorded slightly higher estimated means than females under both strategies. The nearly parallel lines indicate that the effect of instructional strategy was generally similar for males and females, suggesting no substantial interaction effect between instructional strategy and gender. This visual pattern agrees with the ANCOVA result in Table 8, where the treatment-by-gender interaction was not statistically significant, $F(1, 155) = 0.035$, $p = .853$, partial $\eta^2 < .05$.

H_{04}: There is no significant difference in the mean critical thinking skills rating scores of pre-service Basic Science teachers taught using metacognitive scaffolding strategy and those taught using self-questioning strategy.

Table 8: Summary of Analysis of covariance (ANCOVA) of significant difference in mean critical thinking skills rating scores of pre-service Basic Science teachers taught using metacognitive scaffolding strategy and those taught using self-questioning strategy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2075.804[a]	4	518.951	9.198	.000	.192
Intercept	12698.201	1	12698.201	225.076	.000	.592
PrePBSCTT	83.028	1	83.028	1.472	.227	.009
Treatment	1896.830	1	1896.830	33.621	.000	.178
Gender	81.110	1	81.110	1.438	.232	.009
Treatment * Gender	.138	1	.138	.002	.961	.000
Error	8744.690	155	56.417			
Total	818659.000	160				
Corrected Total	10820.494	159				

Result in Table 8 shows that the main effect of treatment was significant, $F(1, 155) = 33.621$, $p < .05$, partial $\eta^2 = .178$. This indicates that there was a significant difference in the critical thinking skills of pre-service Basic Science teachers taught using metacognitive scaffolding and those taught using self-questioning strategy, after controlling

for the pre-test scores. The partial eta squared value of .178 indicates that approximately 17.8% of the variance in the adjusted critical thinking skills scores was associated with the treatment factor.

H_{05}: There is no significant difference in the mean critical thinking skills rating scores of male and female pre-service Basic Science teachers.

The result in Table 8 was also used to test hypothesis five. The result revealed that the main effect of gender was not significant, $F(1, 155) = 1.438$, $p = .232$, partial $\eta^2 = .009$. This indicates that male and female pre-service Basic Science teachers did not differ significantly in their critical thinking skills after controlling for the pre-test scores and treatment. The partial eta squared value of .009 indicates a small effect, with approximately 0.9% of the variance associated with gender.

H_{06}: There is no significant interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills.

The result in Table 8 was also used to test hypothesis six. The result revealed that the interaction effect between treatment and gender was not significant, $F(1, 155) = 0.002$, $p = .961$, partial $\eta^2 < .05$. This indicates that the effect of instructional strategy on pre-service Basic Science teachers' critical thinking skills did not significantly vary according to gender. Thus, gender did not significantly modify the effect of metacognitive scaffolding and self-questioning strategies on critical thinking skills.

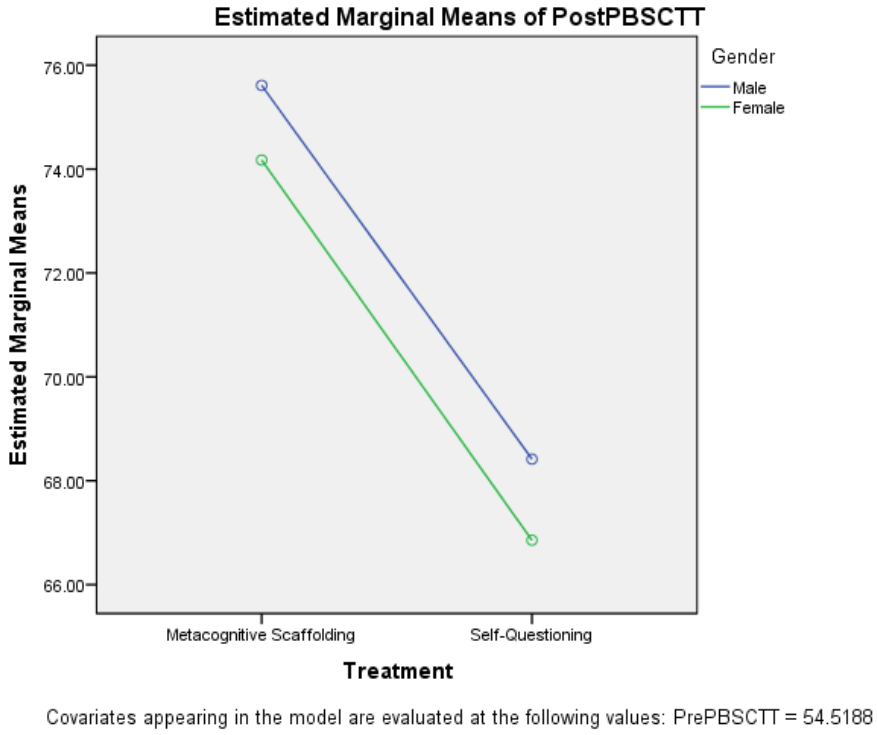

Fig. 2: Graph of the interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills

The profile plot shows that both male and female pre-service Basic Science teachers had higher estimated marginal mean scores in critical thinking skills when taught using metacognitive scaffolding than when taught using self-questioning. Male participants recorded slightly higher estimated means than females under both instructional strategies. The nearly parallel lines indicate that the effect of instructional strategy was generally similar for males and females, suggesting no substantial interaction effect between instructional strategy and gender. This visual pattern agrees with the ANCOVA result in Table 8, where the treatment-by-gender interaction was not statistically significant, $F(1, 155) = 0.002$, $p = .961$, partial $\eta^2 < .05$.

DISCUSSION OF FINDINGS

Effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' digital literacy skills

The finding showed that metacognitive scaffolding and self-questioning strategies improved pre-service Basic Science teachers' digital literacy skills. The metacognitive scaffolding group recorded a higher adjusted mean score than the self-questioning group. This difference was significant indicating that instructional strategy had a

significant effect on digital literacy skills, with metacognitive scaffolding associated with the higher adjusted performance. The finding suggests that digital literacy development is enhanced when learners are provided with explicit support to plan, monitor, regulate and evaluate their learning and use of digital resources.

The finding may be explained by the nature of metacognitive scaffolding, which provides learners with systematic guidance while gradually encouraging them to assume greater responsibility for their learning. In developing digital literacy, learners are often required not only to operate digital tools but also to determine what information or technology is appropriate for a particular task, monitor the effectiveness of their actions, identify errors and evaluate the reliability of information obtained from digital sources. Metacognitive scaffolding creates opportunities for learners to consciously plan these processes, monitor their progress and reflect on the outcomes of their digital activities. Thus, pre-service Basic Science teachers exposed to this strategy may have developed greater awareness of how and why particular digital tools and resources should be used. The higher performance of the metacognitive scaffolding group may also be attributed to the structured support provided during learning. Scaffolding can involve prompts, guiding questions, demonstrations, feedback and gradually reduced assistance. Such support may have enabled the pre-service teachers to overcome difficulties encountered while performing digital tasks. Rather than simply learning how to use digital tools, the learners were encouraged to think about their learning processes and make appropriate decisions concerning the use of digital resources. This is particularly important in Basic Science teacher education, where teachers are increasingly expected to search for, evaluate, organise and communicate scientific information using digital technologies.

The finding is supported by recent evidence on the relationship between metacognitive regulation and digital competence among prospective teachers. For example, Yermekova et al. (2026) found that a 15-week intervention that integrated metacognitive prompts with authentic digital tasks significantly improved both metacognitive awareness and perceived professional digital competence among pre-service teachers. The finding is also consistent with Michalsky (2024), who investigated metacognitive scaffolding among pre-service secondary science teachers. The study found that metacognitive support enhanced pre-service teachers' comprehension and their ability to design higher-order-thinking learning tasks, while also improving their capacity to reflect on and regulate their own learning. The finding further agrees with the findings of Michalsky and Bakrish (2024) whose study reported that learners who received metacognitive self-questioning support during digital literacy activities improved both their learning performance and the accuracy of their judgments about their own learning. The researchers found consistent improvements across reading and mathematical literacy activities conducted in digital environments. Similarly, Şendurur and Yildirim (2019) found that web-based metacognitive scaffolding significantly improved learners' metacognitive skills compared with a no-scaffolding condition. Their study demonstrated that providing learners with structured support during Internet searching can strengthen the metacognitive processes required to search for and process information effectively.

Influence of gender on pre-service Basic Science teachers' digital literacy skills

The finding revealed that both male and female pre-service Basic Science teachers improved in digital literacy skills following the intervention, with male participants recording a slightly higher adjusted mean score than their female counterparts. However, the difference was not significant, indicating that gender did not significantly influence the digital literacy skills of the pre-service Basic Science teachers. This suggests that the intervention provided learning opportunities that were sufficiently accessible to both male and female participants, enabling them to develop comparable levels of digital literacy irrespective of gender. The absence of a significant gender effect may be explained by the increasingly gender-neutral nature of digital learning environments in teacher education. Digital literacy involves competencies such as accessing, evaluating, creating and communicating information through digital technologies, and these competencies can be developed through exposure, practice, guidance and meaningful engagement with digital tools rather than through gender. When male and female pre-service teachers are provided with similar access to digital resources, instructional support and opportunities for practice, differences attributable to gender may become less pronounced. The result therefore suggests that the intervention may have created an equitable learning environment in which both groups were able to acquire and apply digital skills. The present finding is strongly supported by previous empirical evidence. The study by Ünlü, Öztürk, and Yıldırır (2026) examined digital competence among science teacher education students in Türkiye and reported no significant gender difference in students' digital competence. Similarly, Obasuyi (2015) investigated ICT literacy skills among first-year university students at the University of Benin and found that gender did not influence students' ICT literacy skills.

Interaction effect of instructional strategies and gender on pre-service Basic Science teachers' digital literacy skills

The finding indicated that the effect of instructional strategies on digital literacy skills was generally similar for male and female pre-service teachers. The descriptive results showed that males and females performed better under metacognitive scaffolding than under self-questioning, while males recorded slightly higher scores within both strategies. However, the interaction effect between instructional strategies and gender was not significant. This indicates that gender did not significantly modify the effect of the instructional strategies on digital literacy skills.

The absence of a significant interaction suggests that both male and female pre-service teachers were able to benefit from the instructional strategies in a relatively similar manner. This may be because both metacognitive scaffolding and self-questioning provide learners with cognitive and regulatory support that is applicable irrespective of gender. Metacognitive scaffolding guides learners to plan, monitor, evaluate and regulate their learning, while self-questioning encourages learners to actively interrogate information, identify gaps in understanding and evaluate their own learning processes. These processes are not inherently gender-specific and, when appropriately structured by the teacher, can provide comparable opportunities for male and female learners to develop digital competencies.

The finding is consistent with Yermekova et al. (2026), who found that an intervention integrating metacognitive prompts with authentic digital tasks significantly improved pre-service teachers' metacognitive awareness and perceived professional digital competence. The importance of this study to the present finding lies in its demonstration that structured metacognitive support can promote digital competence among prospective teachers without suggesting that its effectiveness is restricted to a particular gender. The result also agrees with Michalsky (2024), who reported that metacognitive scaffolding enhanced pre-service secondary science teachers' comprehension, design of higher-order-thinking tasks and self-regulated learning. These findings suggest that the benefits of metacognitive support arise primarily from the quality and structure of the learning processes it promotes rather than from learners' gender. The present finding also agrees with Michalsky and Bakrish (2024), who found that metacognitive questioning improved learners' performance and the accuracy of their judgments of learning in digital learning environments.

Effect of metacognitive scaffolding and self-questioning strategies on pre-service Basic Science teachers' critical thinking skills

The finding showed that both metacognitive scaffolding and self-questioning strategies improved pre-service Basic Science teachers' critical thinking skills, although the metacognitive scaffolding group recorded a higher adjusted mean score than the self-questioning group. The ANCOVA result further established that the difference between the two instructional strategies was statistically significant. This indicates that instructional strategy has a significant effect on the development of critical thinking skills, with metacognitive scaffolding producing superior performance. The higher achievement of the metacognitive scaffolding group, however, suggests that scaffolding may provide a more comprehensive form of support for critical thinking than self-questioning alone. While self-questioning primarily stimulates learners to generate and respond to questions about their learning, metacognitive scaffolding can provide systematic prompts and guidance across several phases of learning. Learners may be supported to identify a problem, plan an appropriate approach, monitor their reasoning while solving the problem, evaluate the evidence used to reach a conclusion and reflect on the quality of the final decision. This systematic sequence may enable learners to engage more consistently in the cognitive and metacognitive processes underlying critical thinking.

The superiority of the metacognitive scaffolding group is consistent with the finding of Michalsky (2024), who investigated metacognitive scaffolding among pre-service secondary science teachers. The study found that although both the metacognitive scaffolding and comparison groups improved, the group receiving metacognitive support demonstrated greater development in higher-order-thinking pedagogical content knowledge. Metacognitive support also enhanced the participants' comprehension and design of higher-order-thinking tasks as well as their ability to reflect on and regulate their learning. The finding is further supported by Wang, Chen and Yen (2021), who investigated metacognitive scaffolding in simulation-based inquiry in physics. Their study found that incorporating metacognitive prompts into inquiry-based learning produced greater improvement in integrated science process skills and confidence judgments than simulation-based inquiry without the additional metacognitive scaffolding.

Influence of gender on pre-service Basic Science teachers' critical thinking skills

The finding of the study indicated that male and female pre-service Basic Science teachers improved in critical thinking skills following the instructional intervention. Male teachers recorded a slightly higher adjusted mean score than female teachers. However, the difference was not significant. Therefore, gender did not significantly influence pre-service Basic Science teachers' critical thinking skills. The improvement observed among both male and female participants may be attributed to the nature of the instructional strategies employed in the study. Both metacognitive scaffolding and self-questioning require learners to actively engage with learning tasks rather than passively receive information. Learners are encouraged to examine their understanding, identify gaps in knowledge, question assumptions, consider alternative explanations and evaluate the adequacy of their conclusions. Such activities are fundamental to critical thinking and can benefit learners irrespective of gender. The comparable improvement of male and female participants therefore suggests that the instructional approaches created a learning environment that supported the development of higher-order thinking among both groups.

The finding that gender did not significantly influence the critical thinking skills of pre-service Basic Science teachers is consistent with previous empirical evidence. For example, Demiral (2018), in a study involving 200 pre-service science teachers, found that critical thinking skills did not differ significantly according to gender. This finding is particularly relevant to the present study because both studies involved prospective science teachers and examined gender in relation to critical thinking. Similarly, Owusu, Aboagye, and Otami (2024) reported that male

and female pre-service science teachers did not differ significantly in their awareness of critical thinking abilities. Their finding suggests that the development and awareness of critical thinking among prospective science teachers may depend more on educational experiences and university course exposure than on gender.

Interaction effect of instructional strategies and gender on pre-service Basic Science teachers' critical thinking skills

The finding revealed that the effect of instructional strategies on critical thinking skills was generally similar for male and female pre-service Basic Science teachers. Although the descriptive results showed that both male and female participants exposed to metacognitive scaffolding obtained higher scores than their counterparts exposed to self-questioning, and male participants recorded slightly higher scores within both instructional conditions, the interaction between instructional strategies and gender was not significant. This indicates that gender did not significantly moderate the effect of instructional strategies on the critical thinking skills of the pre-service Basic Science teachers. The absence of a significant interaction suggests that the instructional strategies were broadly applicable to both male and female pre-service teachers. Both metacognitive scaffolding and self-questioning require learners to engage actively in the learning process by examining information, questioning assumptions, monitoring understanding, evaluating evidence and reflecting on conclusions. These cognitive processes are fundamental to critical thinking and are not inherently dependent on gender. Therefore, when male and female learners receive comparable instructional support and opportunities to engage in higher-order thinking, they can respond to the strategies in relatively similar ways.

The finding is consistent with Demiral (2018), who found no significant gender difference in the critical thinking skills of pre-service science teachers. The similarity is important because it suggests that gender may not substantially determine how prospective science teachers develop higher-order cognitive abilities. Similarly, Owusu, Aboagye and Otami (2024) reported no significant gender difference in pre-service science teachers' awareness of their critical thinking abilities. These findings provide support for the present result by suggesting that the cognitive processes underlying critical thinking can be developed among male and female prospective science teachers under comparable educational conditions. The result also agrees with the findings of Priyambodo et al. (2026), who examined the roles of academic ability, gender and grade level in the critical thinking skills of pre-service teachers. Their study provides further evidence that critical-thinking performance should not be understood primarily in terms of gender, but rather in relation to the broader learning experiences and individual characteristics of prospective teachers. This supports the present finding that although male participants recorded slightly higher descriptive scores, gender did not significantly change the effectiveness of the instructional strategies.

CONCLUSION

The findings demonstrate that metacognitive scaffolding provides a promising instructional approach for strengthening both digital literacy and critical thinking among pre-service Basic Science teachers. Its effectiveness across gender groups also suggests that it can be adopted as a gender-inclusive strategy in teacher education programmes. The study therefore concludes that systematic support for planning, monitoring, evaluating and reflecting on learning can better prepare prospective Basic Science teachers for the cognitive and digital demands of contemporary science education.

Recommendation

Based on the findings of the study, the following recommendations are made:

1. Teacher educators in colleges of education and universities should integrate metacognitive scaffolding into the preparation of pre-service Basic Science teachers because the strategy was more effective than self-questioning in improving digital literacy and critical thinking skills.
2. Basic Science teacher educators should systematically expose pre-service teachers to metacognitive activities such as planning, monitoring, evaluating, reflecting on learning processes, and regulating problem-solving activities. These activities should be embedded in both theoretical and practical components of teacher education programmes.
3. Curriculum planners and teacher education institutions should include metacognitive scaffolding and related self-regulated learning approaches in Basic Science methods courses and other professional education courses. This would enable pre-service teachers to develop instructional practices that promote higher-order thinking and digital competence among their future students.
4. Teacher educators should provide equal opportunities for male and female pre-service teachers to participate in metacognitive and digital learning activities. Since gender did not significantly influence digital literacy or critical thinking, instructional activities should be designed to be gender-inclusive rather than tailored to one gender.
5. Professional development programmes for lecturers and teacher educators should focus on the effective design and implementation of metacognitive scaffolding, including the use of prompts, reflective questions, feedback, digital learning resources, and structured opportunities for self-monitoring and evaluation.
6. Educational institutions should provide adequate digital resources and supportive learning environments that enable pre-service teachers to practise digital literacy skills while engaging in metacognitive learning activities. Access to appropriate digital tools should be accompanied by guidance on how to use them critically and effectively.

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