EFFECT OF SCALFOLDED METACOGNITIVE ACTIVITIES ON SENIOR SECONDARY SCHOOL STUDENTS' PROBLEM-SOLVING SKILLS IN STEM SUBJECTS

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Abstract

This research paper examined the effect of scaffolded metacognitive activities on the problem-solving skills of students in STEM subjects in senior secondary schools. Quasi-experimental research design was used. A multistage sampling procedure was used for the sample selection. A total of 120 students in senior secondary schools of the two schools randomly selected in Ile-Ife, Osun State, Nigeria participated in the study. The experimental group students were instructed in scaffolded metacognitive activities and the control group students were instructed in the conventional ways of teaching. Problem-solving skills questionnaire was used to collect the data. Analysis of Covariance (ANCOVA) was utilised to compare the post-test problem solving scores and controlling the differences at the pre-test. The findings showed that there was a statistically significant difference in problem-solving skills of the students in the experimental group and those in the control group, such that, students in the experimental group displayed better results than those

in the control group, [$F_{(1, 117)} = 9.029$, $p = .003$]. The study concludes that scaffolded metacognitive activities are an efficient strategy of enhancing problem-solving skills of senior secondary school students in STEM subject. It has been suggested, therefore, that STEM teachers should incorporate scaffolded metacognitive activities throughout classroom learning in order to facilitate increased secondary (high)er-order thinking and more positive problem-solving skills.

Keywords: Scaffolded metacognitive activities; problem-solving skills; STEM education;

Introduction

Science, Technology, Engineering, and Mathematics (STEM) education has problem-solving as one of its core competences widely known to be the crucial for learners academic success and subsequent entry into the global knowledge economy (Liu & Kringos, 2025). According to Thomason and Hsu (2025), current STEM programs do not focus on just knowing disciplinary content but also on higher order thinking abilities that enable students to solve problems, generate solutions and apply knowledge flexibly manner in new context. Consequently, Sun et al. (2025) posits that one of the key objectives of secondary school STEM education is enhancing students problem-solving skills.

In spite of this focus, as shown in numerous educational systems, especially in developing ones, it has been shown according to Tong et al. (2025) that students in the secondary school still exhibit poor problem-solving skills in STEM subjects. Most of the classrooms continue to be teacher-centred, examination-based, and rote-based in their instructional practices, instead of also being cognitive and strategic in their instructional practices (Mudin, 2019). These strategies tend to curtail the ability of students to reconsider their thought processes, keep track of what they know and change strategies in case they are faced with complex or unfamiliar challenges. Eticha, Hunde and Ketema (2025) asserts that

Metacognitive instruction has become one of the instructional methods to receivesignificant attention in overcoming this challenge. Metacognition can be described as the awareness and control of the cognitive processes of learners, i.e. planning, monitoring, and assessing their comprehensiveness when undertaking learning activities (Azevedo, et al., 2022). Studies have indicated that metacognitively aware students are better problem solvers because they have the ability to choose the right strategies, identify mistakes and alter the strategies once they run into challenges(Güner & Erbay, 2021; Reinhard, Felleson, Turner, & Green, 2022; Tachie, 2019). Nevertheless, metacognition is not an automatic process; therefore many learners to be guided by explicit instructional support to develop and implement such skills successfully especially, in cognitively challenging STEM activities (Arianto & Hanif, 2024).

Scaffolding offers a pedagogically viable model of facilitating the acquisition of the metacognitive skills (Wang, Gao & Chen, 2024). Based on sociocultural learning theory, scaffolding involves providing temporary support and guidance to learners in undertaking intricate activities until they can undertake the same tasks on their own. Ngongnpah and Oni (2025) state that scaffolding can be implemented when used with metacognitive instructions with a few prompts (planning), guided questions, strategy modeling, strategy-use feedback, and reflections. Scaffolded metacognitive activities therefore, form organised learning conditions that bring forth cognitive and problem solving processes to be explicit so that students internalise effective practices with time. (Siregar, 2025).

Several empirical research has shown that integrating scaffolded metacognitive activities in teaching has the potential to enhance students' performance in STEM-related subjects, when it comes to solving problems. Such interventions are observed to improve the capacity of the learners in analysing issues, choosing the means of doing so, and reviewing the solution options. However, most of the available literature is based on the developed world and secondary education settings and there are relatively fewer literature on the

effectiveness of scaffolded metacognitive strategy in the senior secondary level in sub- Saharan Africa. This disparity is observed especially in Nigeria where continuous poor performance in STEM subjects has cast doubt over the suitability of current teaching and learning methods.

Senior secondary school learners in the Nigerian setting are supposed to achieve problem-solving skills in STEM subjects as a national curriculum requirement and secondary (high)-stakes assessments. Nonetheless, investigations conducted by the examination authorities and the classroom-based research propose that a significant number of learners find it challenging when dealing with assignments that involve the use of reasoning, application, and critical thinking (Yusuf et al, 2024). These are further exacerbated by high classroom sizes, inadequate instructional materials and inadequate teacher training in learner-based pedagogies. There is thus a critical necessity of empirically validated instructional strategies that can improve the ability to solve problems in the real classroom contexts (Danlami et al. 2025).

It is against this background that scaffolded metacognitive activities provide an opportunity to enhance the learning outcomes in STEM with secondary school students in Nigeria. Teachers can potentially provide students with more effective problem-solving strategies through the explicit metacognitive instructions integrated into the regular classroom instruction, without necessarily upsetting the existing curricular frameworks.

This aspect is fulfilled by the current study, which investigates the impact of scaffolded metacognitive activities on the problem-solving ability of senior secondary school students with the STEM subjects (Wang 2024). The study is conducted in the forms of a quasi-experimental pre-test- post-test control group design where the authors compare the performance of students who studied problem-solving using a scaffolded metacognitive instructional program and

those who studied problem-solving using conventional instructional programs. By adjusting the initial variations in the problem-solving skills of students, the study may be considered as a strong evidence as to the role of scaffolded metacognitive activities in the development of students in solving problems within the context of STEM teaching.

This research is likely to add to the existing literature on metacognitive scaffolding and STEM education and provide practical implications on how to enhance the performance of secondary school students in solving problems by using metacognitive scaffolding. Specifically, the research introduces contextually pertinent evidence that could be used in instructional practice and curriculum development in Nigeria and other learning institutions.

Objective One: Examine the effect of scaffolded metacognitive activities on students' problem-solving skills in STEM subjects.

Hypothesis (H_0): There is no significant difference in the problem-solving skills of students in STEM subjects when taught using scaffolded metacognitive activities and conventional strategy

Methodology

In this article, a quasi-experimental research design of the non-equivalent pre-test, post-test control group research type was chosen to examine how scaffolded metacognitive activities affect the problem-solving abilities of senior secondary school learners in STEM subjects. The design enabled one to measure the level of problem-solving skills possessed by students prior to and following the intervention, and compare the results of the experimental and the control group. Pre-test scores were used as covariate to make sure that initial mean difference in student ability is controlled statistically to offer a statistical meaning of the effect of the intervention (Badolo, et al. (2025). The study design is structurally shown as:

O_1 K_1 O_2 Experimental Group (Scaffolded Metacognitive Method)
O_3 K_2 O_4 Control Group (Conventional Method)
Where O_1 and O_3 are the pre-test observations for the two groups, O_2 and O_4 are the post-test observations for the groups.
K_1= Experimental treatment using Scaffolded Metacognitive Activities (SMS)
K_2= Control Group using Conventional Method (CM)

Variables of the study
Three variables were examined in the study, they are:

1. **Independent Variable:** The mode of instruction manipulated at two (2) levels, namely:
a. Scaffolded Metacognitive Activities Method
b. Conventional Method
2.) **Covariate:** Pre-test scores from the questionnaire to account for baseline differences.
3.) **Dependent Variable:** There is one dependent variable in the study, namely:
a. Problem Solving Skills

All students of senior secondary schools studying STEM subjects in Ile-Ife central Local Government Area of Osun State, Nigeria were included as the population in this study. Out of such a population, two schools were sampled randomly through simple random sampling. The study encompassed all the intact science classes. The science classes were chosen because they offer STEM-related subjects (Biology, Physics, Chemistry, Mathematics, Data Processing, and so on) in the selected schools. One hundred and twenty students were used; 60 students in intact classes formed the experimental group and 60 students in other intact classes formed the control group.

A Problem-Solving Skills Questionnaire (PSSQ) was developed specifically to collect data in the selected study was used for the study. To make sure that the content is valid, the instrument was

checked by the experts in the fields of STEM education and educational psychology. Cronbach Alpha was also used to determine the reliability of the instrument and gave a coefficient of 0.82, which is high internal consistency.

Pre-Test Administration: The pre-test was done on the problem-solving skills to both experimental and control groups as a way of establishing the baseline performance.

Intervention:
Experimental Group: Students were taught through scaffolded metacognitive activities which included guided problem-solving, reflection prompting, carrying out of strategy modelling, and feedback about solution strategies.

Control Group: Students were provided with conventional teaching, that is, with regular teacher-delivered lessons and with no overt metacognitive scaffolding.

Post-Test Administration: The problem solving post-test was administered to all the students similar to the intervention conditions.

Method of Data Analysis
Analysis of covariance (ANOVA) was employed in the analysis of data to establish the effect of scaffolded metacognitive activities on post-test scores in problem-solving and had to adjust the score differences at pre-test stage. The statistical tests was performed at = 0.05 with the help of the Statistical Package of Social Sciences (SPSS) version 28.

Result
Hypothesis (Ho): There is no significant difference in the students' problem-solving skills of students in STEM subjects when taught using scaffolded metacognitive activities and conventional strategy

The result of the tested hypothesis is in the Table 1.

Table 1: Analysis of Covariance on the impact of scaffolded metacognitive activities on students' problem-solving skills

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta 0 Squared
Corrected Model	16.401[a]	2	8.200	166.141	<. 001	. 740
Intercept	14.438	1	14.438	292.522	<. 001	. 714
Pre-test	16.236	1	16.236	328.938	<. 001	. 738
Treatment Group	. 446	1	. 446	9.029	. 003	. 072
Error	5.775	117	. 049			
Total	835.717	120				
Corrected Total	22.176	119				

a. R Squared = .740 (Adjusted R Squared = .735)

Table 1 above showed the result of A-one-way analysis of covariance (ANCOVA) conducted to determine the impact of scaffolded metacognitive activities on students' problem-solving skills, controlling for pre-test scores. The independent variable was the group (experimental or control), the dependent variable was the post-test problem-solving score, and the pre-test score was used as a covariate. The ANCOVA results indicated a statistically significant difference in post-test problem-solving skills between the experimental and control groups after controlling for pre-test scores, $F(1, 117) = 9.029, p = 0.003$.

Pairwise Comparisons of Adjusted Post-Test Problem-Solving Scores

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]
Scaffolded Metacognitive Activities	Conventional Method Scaffolded	.086*	.029	.003	.029
Conventional Method	Metacognitive Activities	-.086*	.029	.003	-.143

The pair wise comparisons between the adjusted post test scores of the problem-solving activities showed that there was a statistically significant difference between the students who were taught through scaffolded metacognitive activities and those taught through the conventional instructional method after adjusting the pre-test scores of the students. In particular, students in the scaffolded metacognitive activities condition scored significantly (high) on problem-solving scores, adjusted mean scores, than students taught using the conventional method (Mdiff = 0.086, SE = 0.029, p =.003).

The 95 percent confidence interval of the mean difference shows that the actual difference in the adjusted scores is within the positive values which supports the strength of the effect and the direction of the effect in favour of the scaffolded metacognitive activities. The comparison (conventional method vs scaffolded metacognitive activities) showed the similar and negative mean difference (Mdiff = -0.086) which once again supports the better rank of the scaffolded metacognitive instructional tool. These results give empirical support to the idea that scaffolded metacognitive activities can considerably improve problem-solving ability of students in STEM disciplines

Discussion

This research investigated the effects of scaffolded metacognitive tasks on secondary school students during the process of solving

problems in STEM subjects. These findings indicated that learners who were taught in metacognitive activities performed much better than the learners that were instructed through conventional strategy. This was after taking into consideration their initial test scores. In essence, it insinuates that the increase in problem solving skills was a result of the teaching method rather than the variation in the abilities of the students prior to the study.

Scaffolded metacognitive activities helps in advising the students to strategise, keep track and analyze their personal steps towards problem solving. Solving the problems in STEM at secondary school level is not simply getting facts at hand, it is critical thinking. Students should have the ability to evaluate issues, select the appropriate activities, monitor their progress, and assess their performance. Such scaffolded exercises render all that, even more understandable and approachable as it enables students to face STEM problems in a more coordinated and planned manner than the typical approach to teaching.

The findings of this study align with available literature that has been able to identify the advantages of metacognition and scaffolding to enhance the problem-solving abilities of students. According to other research carried out in the past, the instructional strategies with metacognitive prompts and guided reflection can actually result in better performance among students in science and mathematics (Sijmkens et al., 2023; Silver et al., 2023; Stanton et al., 2021). Teachers can make students internalize new ideas to apply in their new situations by assisting students to think through their processes.

Another theory related to Vygotsky and other researchers states that learning is best achieved when teaching takes place within the limits within which a learner can reasonably operate under guidance (Bodrova and Leong, 2024; Taber, 2025). scaffolded metacognitive activities perfectly aligns with this theory since they have a built-in support system that will be gradually withdrawn obased on the increase in competency. By providing this gradual support, students

are motivated towards becoming more independent in their ways of thinking.This is critical especially towards effective problem solving in STEM subjects.

It is also the case that the results of this study are congruent with a number of other studies. As an illustration, it has been demonstrated that students who are exposed to learning with metacognitive tasks achieve better performance on the tasks that involve reasoning and logical thinking as compared to their counterparts (Akbayir and Topcul, 2021; Li et al., 2023). These scaffolding tasks assist the students in becoming more conscious of their thoughts and learn to have more control over the learning process in case of complex problems.

Also, the findings indicate that the conventional teaching methods are not adequately designed develop effective problem-solving skills in learners since they tend to be teacher-centered in the descricption and demonstration process. Though some of these approaches are satisfactory in terms of content delivery. They still tend to offer few chances to students to think about what they have acquired, practice with their ideas, and learn in the course of making mistakes. Therefore, students are unable to meet up with new or difficult STEM challenges.

Although numeerous studies have given evidences of the effectiveness of metacognitive instructional strategy. Other scholars argue that scaffolded metacognitive activities adds to students cognitive load especially in cases where the learner does not have a good background knowledge. In such situations, the scaffolding that was supposed to facilitate learning, on the contrary, complicates the learning process (Ahmadi Safa and Motaghi, 2024; Reiser, 2023; Vo et al., 2022). Instructions that are too lengthy or perceived incorrectly can suffocate students instead of help them to learn effectively.

On the same note, other researchers indicate that the effectiveness metacognitive activities is based on the competence of the teacher,

the time taken, and the motivation of the students when engaging in the reflective process (Cheng and Chan, 2021; Silver et al., 2023). As such scaffolded metacognitive activities must be implemented in a manner relevant to the particular educational context.

Conclusion

The findings of the study showed that scaffolded metacognitive activities possess a great potential in enhancing the problem solving skills of senior secondary school students in STEM subjects. Although the post-test scores were corrected by considering the differences between the two baseline scores students in scaffolded metacognitive instructional strategy scored secondary in problem-solving relative to their counterparts who received instructions using conventional means. The scaffolding is actually an important aspect of teaching particularly in the learning of STEM subjects by students at the secondary school levels. It helps them be critical and strategic and to consider their problem-solving abilities. This approach appears to be an effective way of increasing their participation and concentration in the field when they have to perform seemly difficult tasks. It is because, it provides them with the suitable assistance when they need it.

In practice, the study demonstrates that it is possible to effectively offer scaffolded metacognitive tasks even in the general classroom context within the structure of senior secondary (high) schools. The intervention also entails relatively minor modifications to the instructional practice and results in the significant improvement of the problem-solving abilities of students, which presupposes that it can be feasible and maintained as an instructional intervention.Therefore, scaffolded metacognitive activities represent an effective teaching strategy, which is evidence-based and may be implemented to develop problem-solving skills in STEM learning. The study provides empirical findings to curriculum developers, teachers and education policy-makers that they should take into account in their teaching of STEM education, which involve the application of organized metacognitive scaffolding in teaching to

attain more successful learning outcomes. The future research could be directed to the following issues: effects of such interventions in the long term, their application to other STEM fields, and their effects on other significant skills, such as creativity, teamwork, and self-management.

Recommendation

According to the results of the current research, a number of recommendations are given to enhance the instructional practice and future studies in STEM education:

I. The lesson plans of teachers teaching STEM subjects ought to include scaffolded metacognitive tasks that involve guided reflection, self-questioning questions, and problem-solving checklists.

ii. The teachers ought to be put through the professional development training programs on how to design, implement and evaluate the scaffolded metacognitive strategies.

iii. Educators can be taught through workshops and ongoing in-service training programs on the need to balance between offering assistance and progressively removing scaffolds to develop the independent problem-solving ability.

iv. Scaffolded metacognitive activities ought to be incorporated in the STEM curricula at the senior secondary school level by curriculum developers.

v. The activities needs to be based on the national learning objectives and assessment standards, so the development of metacognitive skills should be the complement to subject-specific skills.

vi. Education policy-makers ought to be aware that metacognition is useful in promoting problem-solving skills and promote the use of systematic models of metacognitive scaffolding in schools.

vii. The effects of scaffolded metacognitive activities on the academic performance of the students and whether they can be transferred to the real world problem-solving situations

should be investigated in further studies.

viii. Cross-disciplinary research in other fields of STEM (e.g., mathematics, physics, biology) might give hints of how the metacognitive scaffolding might be adapted to those disciplines.

Implications of the Findings

In brief, this study demonstrates that students cannot simply be overloaded with content in order to improve their problem-solving skills. Instead, teaching strategies that genuinely support the ways in which students think and reflect on their own learning need to be used. Based on these findings, scaffolded metacognitive activities appear to assist in improving students' problem-solving abilities, particularly when they are confronted with difficult and abstract concepts in STEM subjects.

On the part of teachers, metacognitive and reflection activities should be incorporated into everyday classroom instruction. This incorporation must be seen as an essential one .For curriculum designers, educational reformers, and policy makers, this study provide strong evidence for the integration of metacognitive scaffolding into STEM programmes both at the secondary school level and within pre-service teacher education.

Furthermore, the study indicates that using scaffolded metacognitive activities can significantly support senior secondary school students in developing problem-solving skills in STEM subjects, most especially in comparison with conventional teaching strategies. Although, Some exising literatures highlights the several limitations associated with metacognitive strategies .This study suggest that when scaffolded metacognitive activities are implemented properly, they can substantially enhance student learning and problem-solving within STEM education.

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