ENHANCING METACOGNITIVE AWARENESS AND SELF-REGULATION IN STEM LEARNING THROUGH SCAFFOLDED METACOGNITIVE ACTIVITIES: EVIDENCE FROM SECONDARY SCHOOLS IN ILE-IFE, OSUN STATE

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Abstract

The study examined the use of scaffolded metacognitive activities as a strategy for promoting STEM education among secondary school students. Specifically, it investigated how scaffolding metacognitive activities can enhance students' metacognitive awareness and self-regulation during STEM learning. A quasi-experimental research design was adopted for the study. The population comprised all (N =5730) Senior Secondary School students offering STEM-related subjects (Mathematics, Physics, Chemistry, and Biology) in Ile-Ife, Osun State. A total of 120 students participated in the study and were divided into two groups: an intervention group exposed to scaffolded metacognitive activities and a control group taught using the conventional STEM teaching approach. Participants were selected through a multistage sampling technique. Data were collected using the Metacognitive Awareness and Self-Regulation in STEM Learning Scale (MASR–STEM) and the Feasibility of Integrating Scaffolded Metacognitive Activities into the STEM Curriculum Scale (FISMA–STEM). The collected data were analysed using descriptive statistics and Analysis of Covariance (ANCOVA). The findings revealed that scaffolded metacognitive activities had a statistically significant effect on students' metacognitive awareness and self-regulation, $F(1,117) = 8.259$, $p = .003$. However, the magnitude of the effect was relatively small, as indicated by the partial eta squared value ($\eta^2 = .072$), suggesting that the intervention accounted for approximately 7.2% of the variance in students' post-test metacognitive awareness and self-regulation after controlling for pre-test scores. Another important finding of the study relates to the feasibility of integrating scaffolded metacognitive activities into the existing STEM curriculum. The results showed moderate approval from teachers and students (33.3%) regarding the integration of such activities, although some challenges related to instructional resources were identified (41.7%).

The study therefore concludes that scaffolded metacognitive activities have the potential to improve students' metacognitive awareness and self-regulation in STEM learning, although the magnitude of the effect suggests that such activities should be implemented alongside other supportive instructional strategies. The findings imply that incorporating structured metacognitive scaffolding within STEM classrooms may support the development of students' reflective learning skills, strategic thinking, and independent learning behaviours, thereby contributing to more effective STEM teaching and learning practices in secondary schools.

Keywords: *scaffolded metacognitive activities, STEM education, metacognitive awareness and self-regulation*

Introduction

The fast development of technologies that was within the scope of the 21st century presupposes the presence of a highly-qualified workforce with solid background in Science, Technology, Engineering, and Mathematics (STEM). In its fight towards attaining sustainable development and economic growth, Nigeria has recognised the importance of STEM education in fostering innovation, problem-solving skills, and critical thinking skills (Onoshakpokaiye & Avwiri, 2025). A senior secondary school is an important component of this educational procedure that forms a direction of students to professional careers and further education. The STEM curriculum has been long-standing content-based, with more focus on the acquisition of knowledge by rote and memorization (Moses, 2023). Even though basic knowledge remains important, it is not enough to equip students in order to survive in a complex and dynamic world. It has become clear that the paradigm shift towards a more holistic approach to STEM education is very much required (Jolaoluwa et al., 2024). This transformation requires the emphasis on higher-order thinking which comprises critical thinking, problem-solving, creativity, and innovation.

Nevertheless, despite the recognized importance of STEM education in national development, STEM education implementation in Nigeria continues to face challenges such lack of resources, insufficient training of teachers, and poor student involvement (Umar, 2019). As a result, students often demonstrate limited critical thinking ability, weak problem-solving competence, and low engagement in STEM subjects. Although several policy discussions have continually emphasize the provision of infrastructure and learning resources, less attention has been given to the cognitive processes that support meaningful STEM learning. In particular, there is limited integration of instructional practices that intentionally develop students' ability to regulate and reflect on their own thinking. Consequently, a major gap in current STEM pedagogy in Nigeria is the insufficient emphasis on metacognitive development within classroom instruction.

Metacognitive competence is increasingly recognized as a critical element of effective learning because it enables students to plan, monitor, and evaluate their thinking processes during learning activities (Rivas et al., 2022). Within STEM education, these abilities are especially important because students are frequently required to analyze complex problems, evaluate alternative solutions, and apply conceptual knowledge to unfamiliar situations. However, many STEM classrooms still do not deliberately incorporate structured metacognitive activities into instruction. When such activities are used, they are often implemented inconsistently or without sufficient pedagogical guidance. This situation limits their effectiveness in fostering sustained metacognitive awareness and self-regulation among learners.

One promising instructional approach that can address this limitation is the integration of scaffolded metacognitive activities into STEM teaching. Scaffolding, grounded in Vygotsky's sociocultural theory of learning, involves the provision of temporary instructional support that helps learners perform tasks that they may not initially be able to accomplish independently (Sarmiento-Campos et al., 2022). Through carefully structured guidance such as reflective questioning, think-aloud modeling, guided problem solving, and structured self-evaluation, teachers can gradually support

students in developing the skills needed to regulate their own learning processes. As learners gain competence, this support is withdrawn as they increase in learning, thereby promoting independence and deeper cognitive engagement. Scaffolded metacognitive activities address the pedagogical gap in STEM education because they simultaneously support conceptual understanding, critical thinking, and learner autonomy.

Existing research has demonstrated that scaffolding strategies can improve students' awareness of their thinking processes and enhance their ability to regulate learning (Gunawardena & Wilson, 2021; Jia et al., 2025). Similarly, studies have shown that structured metacognitive activities such as reflective questioning, goal setting, and self-assessment can significantly improve students' learning outcomes and critical thinking abilities (Valencia-Vallejo et al., 2019; Akcaoğlu et al., 2023). Despite these findings, there remains limited empirical evidence on how scaffolded metacognitive activities function within STEM classrooms in the Nigerian secondary school context. In particular, few studies have examined how such instructional strategies influence students' metacognitive awareness and self-regulation in real classroom settings.

Given the ongoing efforts to strengthen STEM education in Nigeria, especially at the secondary school level where foundational scientific thinking is developed, it is important to explore pedagogical strategies that can actively promote higher-order cognitive skills among learners. The integration of scaffolded metacognitive activities represents a potentially effective approach for addressing current instructional limitations by helping students become more reflective, strategic, and independent learners. However, empirical research investigating this approach within Nigerian STEM classrooms remains scarce.

Therefore, this study seeks to contribute to the existing body of knowledge by examining the relationship between scaffolded metacognitive activities and students' metacognitive awareness and self-regulation among senior secondary school students in Osun State, Nigeria. By focusing on the instructional role of scaffolding in supporting metacognitive development, this study advances both theoretical and practical understanding of how structured pedagogical support can enhance cognitive engagement in STEM learning. The findings are expected to provide insights that can inform instructional practice, curriculum development, and teacher training aimed at strengthening higher-order thinking and independent learning in STEM education in Osun State.

Objectives of the Study

This study aims to investigate the potential of scaffolding metacognitive activities as a strategy to enhance STEM education among senior secondary school students in Osun State. Furthermore, the specific objectives of this study are to:

i. investigate the feasibility of integrating scaffolded metacognitive activities into the existing STEM curriculum in Osun State; and

ii. explore how scaffolding can improve students' metacognitive awareness and self-regulation in STEM learning.

Research Question

i. To what extent is it feasible to integrate scaffolded metacognitive activities into the existing STEM curriculum in Osun State secondary schools?

Research Hypothesis

i. There is no significant difference on the Metacognitive Awareness and Self-Regulation of senior secondary school students in STEM subjects when taught using the scaffolded metacognitive activities and conventional method in Osun State, Nigeria.

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 metacognitive awareness and self-regulation among senior secondary school learners in STEM subjects. The design enabled one to measure the level of metacognitive awareness and self-regulation 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 good meaning of the effect of the intervention. The study design is structurally shown as:

O_1 K_1 O_2 Experimental Group (Scaffolded Metacognitive Strategy)

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 Strategy (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 Strategy

b. Conventional Method

2.) Covariate: Pre-test scores from the questionnaire to account for baseline differences.

3.) Dependent Variable: There are two dependent variables in the study, namely:

a. Metacognitive Awareness and Self-Regulation

All students of senior secondary schools studying STEM subjects in Ile-Ife, Osun State, Nigeria were included as the population in this study. The total number of all senior secondary schools students studying STEM subjects in Ile-Ife, Osun State, Nigeria was 5730 (L.I.E, 2026). A multi-stage sampling procedure was employed to select the participants. In the first stage, two secondary schools were selected from the list of registered secondary schools in Ile-Ife using simple random sampling. The use of simple random sampling at this stage ensured that each eligible school had an equal chance of being selected for the study.

In the second stage, intact science classes from the selected schools were used. The use of intact classes was considered appropriate because it allowed the researcher to implement the intervention within the natural classroom setting without disrupting existing school structures. The science classes were chosen because they offer STEM-related subjects (Biology, Physics, Chemistry, Mathematics, Data Processing, and so on) in the selected schools. A total of (120) One hundred and twenty students were used; 60 students in the experimental group and 60 students in the control group.

The selected schools were chosen because they offer a full range of STEM-related subjects and possess functional science classrooms, which made them suitable environments for implementing scaffolded metacognitive activities within STEM instruction. In addition, the schools had comparable academic structures, similar curriculum coverage, and similar student population characteristics. This helped in reducing contextual differences that could influence the outcome of the intervention. Selecting schools with similar instructional environments helped ensure that any observed differences in learning outcomes could be more reasonably attributed to the instructional strategy rather than institutional differences.

Before the intervention the pre-test was done on the Metacognitive Awareness and Self-Regulation to both experimental and control groups as a way of establishing the baseline performance. The intervention was conducted over a six-week instructional period, during which both groups received lessons covering similar STEM learning tasks.

Students in the experimental group were taught through scaffolded metacognitive exercises, such as guided problem-solving, reflection prompting, carrying out of strategy modelling, and feedback about solution strategies. While students in the control group were provided with conventional teaching, that is, with regular teacher-delivered lessons and with no overt metacognitive scaffolding.

At the end of the intervention period the problem-solving post-test was administered to both groups in order to determine the effect of the instructional strategies on students' metacognitive awareness and self-regulation

The Metacognitive Awareness and Self-Regulation in STEM Learning Scale (MASR–STEM), as well as Feasibility of Integrating Scaffolded Metacognitive Activities into the STEM Curriculum Scale (FISMA–STEM) were used to collect data in the selected schools for the study. The researcher created the Feasibility of Integrating Scaffolded Metacognitive Activities into the STEM Curriculum Scale (FISMA-STEM) to evaluate the perceptions of the stakeholders regarding the feasibility, preparedness, and supporting the presence of scaffolded metacognitive activities in secondary school STEM curricula. The instrument has 20 items rated on a four-point Likert scale where Strongly Agree (4) is the highest scale and Strongly Disagree (1) is the lowest. All the items deal with major aspects of feasibility, such as perceived benefits of instruction, teacher willingness, student flexibility, resource availability, administrative encouragement, curriculum alignment, and cost-effectiveness. The scale scores higher are associated with more perceived possibility to incorporate scaffolded metacognitive activities in STEM education.

The researcher designed the Metacognitive Awareness and Self-regulation in STEM Learning Scale (MASR-STEM) to test the level of metacognitive awareness and self-regulatory behaviours among students in STEM learning. The instrument aims at measuring the awareness of the cognitive processes in the learners, their planning, monitoring and evaluating of learning tasks, and their capacity to control the effort, learning strategies and learning behaviours when performing STEM tasks. The MASR-STEM is a 20-item scale with a four-point Likert scale where Strongly Agree (4) is positioned on the right-hand side and Strongly Disagree (1) on the left-hand side. The higher the rates of the scale, the greater the metacognitive awareness and self-control during the STEM learning. The items capture major dimensions of metacognition and self-regulated learning that have frequently been found in the literature, such as learning strategy awareness, goal setting, self-monitoring, reflecting, strategy regulation, time management, and proactive help-seeking.

The instrument combines two constructs, which are interrelated, conceptually:

Metacognitive Awareness describes the cognition of the learners (that is, their knowledge) about their cognitive processes, their strengths and weaknesses, their knowledge of the strategies, and their reflections about the problem-solving strategies in STEM activities. Self-Regulation, which involves the skills of learners to plan the learning process, control progress, control effort, control outcomes, and change strategies to increase performance in STEM learning practices.

The MASR-STEM content was based on the known theoretical models on metacognition and self-regulated learning, specifically the models put forward by Flavell (1979), Zimmerman (2000), and the next-generation researchers that focus on planning, monitoring, and evaluation as the essential aspects of an effective learning process. Expert review of the scale was done to establish relevance of the content, clarity, and relevance to the objectives of the study and the reliability analysis was done to establish the internal consistency of the scale before it could be used in the data collection process.

The MASR-STEM offers context sensitive approach to studying the effect of instructional strategies on students' awareness and control of learning processes in STEM instruction and learning, e.g., scaffolded metacognitive activities. Its design renders it to be applicable in the situations of secondary schools and to be applicable to further validation and application of the study in corresponding educational studies.

To make sure that the content is valid, the instrument was checked by 3 experts in the fields of STEM education and educational psychology. In addition, Cronbach Alpha was also used to determine the reliability of the instrument and MASR-STEM gave a coefficient of 0.82, and FISMA-STEM yielded 0.76, which are secondary (high) internal consistency.

Method of Data Analysis

Analysis of covariance (ANCOVA) 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 were performed at = 0.05 with the help of the Statistical Package of Social Sciences (SPSS) version 27.

Results

Research Question 1: To what extent is it feasible to integrate scaffolded metacognitive activities into the existing STEM curriculum in Osun State secondary schools?

In a bid to test the hypothesis, data collected on impact of scaffolded metacognitive activities on students' Metacognitive Awareness and Self-Regulation were analyzed using descriptive statistics. The results are presented in Table 1.

Table 1: Feasibility of Integrating Scaffolded Metacognitive Activities (N = 120)

Category	Level	Frequency	Percentage (%)
Students' Performance	Low	25	20.8
	Average	50	41.7
	High	45	37.5
Reception by Schools, Teachers and Students	Low	40	33.3
	Average	40	33.3
	High	40	33.3
Resources	Low	30	25.0
	Average	50	41.7
	High	40	33.3
Curriculum	Low	25	20.8
	Average	55	45.8
	High	40	33.3

Data collected on the feasibility of integrating scaffolded metacognitive activities in terms of improving student performance were computed and the minimum and maximum scores obtained in this scale were 10 and 40 respectively. Responses on the scale 10-20 were adjudged as having "Low Feasibility". Responses on the scale 21-30 were adjudged as having "Average Feasibility". Responses on the scale 31-40 were adjudged as having "High Feasibility"

The Results from Table 1 showed that of a total of 120 respondents, 20.8% showed a low belief in the feasibility of integrating scaffolded metacognitive activities in terms of improving student performance, 41.7% showed average belief, and 37.5% showed high belief.

While regarding feasibility of integrating scaffolded metacognitive activities in terms of reception by schools, teachers and students 33.3% believe schools, teachers, and students will show low support. While 33.3% believe the support will be average, and 33.3% believe it will be high.

Furthermore, considering the feasibility of integrating scaffolded metacognitive activities in terms of resources 25.0% indicated that schools have the resources needed to implement scaffolded metacognitive activities, while 41.7% remained neutral. However, 33.3% of the respondents felt that their schools lacked the necessary resources to support such activities effectively.

Finally, regarding the feasibility of integrating scaffolded activities into the current STEM curriculum, 20.8% believed the curriculum could accommodate these activities without significant changes. However, 45.8% were neutral, and 33.3% expressed concerns about the alignment of scaffolded activities with the existing curriculum.

Hypothesis One: There is no significant difference in the metacognitive awareness and self-regulation of senior secondary school students in STEM learning when taught using the scaffolded metacognitive activities in Osun State, Nigeria.

In a bid to test the hypothesis, data collected on influence of scaffolded metacognitive activities on students' metacognitive awareness and self-regulation were subjected to Analysis of Covariance

(ANCOVA) using SPSS Statistics. The results are presented in Table 2.

Table 2: Analysis of Covariance on the effect of scaffolded metacognitive activities on students' metacognitive awareness and self-regulation

Sources	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	16.416[a]	2	8.700	166.909	< .001	.770
Intercept	14.881	1	14.881	299.319	< .001	.715
Pre-test	16.160	1	15.816	310.339	< .001	.740
Treatment Group	0.445	1	0.445	8.259	.003	.072
Error	6.004	117	0.051			
Total	916.000	120				
Corrected Total	31.400	119				

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

Table 2 presents the result of a one-way Analysis of Covariance (ANCOVA) conducted to determine the effect of scaffolded metacognitive activities on students' metacognitive awareness and self-regulation while controlling for pre-test scores. In this analysis, the treatment group (experimental and control) served as the independent variable, the post-test metacognitive awareness and self-regulation score served as the dependent variable, and the pre-test score was used as the covariate to control for baseline differences between the groups.

The result of the ANCOVA indicated that pre-test scores significantly influenced the post-test scores, $F(1,117) = 310.339$, $p < .001$, suggesting that students' initial level of metacognitive awareness and self-regulation contributed substantially to their post-intervention performance. After controlling for these baseline differences, the treatment effect remained statistically significant, $F(1,117) = 8.259$, $p = .003$. This result indicates that students exposed to scaffolded metacognitive activities differed significantly in their post-test metacognitive awareness and self-regulation compared with those taught using the conventional method. Based on this finding, the null hypothesis was rejected, indicating that scaffolded metacognitive activities had a statistically significant effect on students' metacognitive awareness and self-regulation.

However, the magnitude of the treatment effect, as indicated by the Partial Eta Squared value ($\eta^2 = .072$), suggests a small to modest effect size. This implies that although scaffolded metacognitive activities significantly influenced students'

metacognitive awareness and self-regulation, the proportion of variance in the dependent variable explained by the treatment was relatively limited. In practical terms, the intervention accounted for approximately 7.2% of the variance in students' post-test metacognitive awareness and self-regulation after controlling for pre-test scores.

The relatively small effect size suggests that while scaffolded metacognitive activities contribute positively to improving students' metacognitive awareness and self-regulation, other factors such as prior learning experiences, teacher instructional practices, classroom environment, and students' individual learning characteristics may also play important roles in shaping metacognitive development. Nevertheless, the statistically significant treatment effect indicates that scaffolded metacognitive activities remain a meaningful instructional approach for supporting the development of students' metacognitive skills within STEM learning contexts

Table 3: Pairwise Comparisons of Adjusted Post-Test Metacognitive Awareness and Self-Regulation Scores

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]
Scaffolded Metacognitive Activities	Conventional Method	.088*	.031	.003	.026
Conventional Method	Scaffolded Metacognitive Activities	-.088*	.031	.003	-.150

The adjusted post-test performance of metacognitive awareness and self-regulation indicated that there was a statistically significant difference between the students that were taught through scaffolded metacognitive activities and those taught through the traditional instruction technique after the adjustment of pre-test scores. The scaffolded metacognitive activities group scored much higher in terms of adjusted mean scores than the conventional method one (Mdiff = 0.088, SE = 0.031, p =. 003).

The 95 percent interval of the mean difference between the scores of adjusted post-test metacognitive awareness and self-regulation confirms that the interval of adjusted score variation is positive, which is confirming the reliability and direction of the effect being positive in favour of the scaffold metacognitive instruction. The negative mean difference (MD iff = -0.088) between the conventional method and scaffolded metacognitive activities obtained through the reverse comparison of both conditions contributes into the effectiveness of the latter metacognitive methodology.

These findings are good indicators that scaffolded metacognitive activities have a great effect on the metacognitive awareness and self-regulation in STEM learning when initial differences are statistically controlled.

Discussion of Findings

The results of this study provide evidence on the effectiveness of scaffolded metacognitive activities and the extent to which they influence students' metacognitive awareness and self-regulation in STEM learning. The analysis of the one-way ANCOVA revealed that scaffolded metacognitive activities had a statistically significant positive effect on students' metacognitive awareness and self-regulation. When the pre-test scores were controlled for, students in the experimental group who were exposed to scaffolded metacognitive activities demonstrated higher post-test scores compared to those in the control group who were taught using the conventional method. This finding suggests that structured scaffolding of metacognitive processes supports students in becoming more aware of their thinking processes and

more deliberate in regulating their learning during STEM tasks.

The result of this study is consistent with existing literature which has emphasized the role of scaffolding in strengthening metacognitive development. For instance, Jia et al. (2025) reported that scaffolded instructional approaches within problem-based learning environments enhance students' metacognitive skills by supporting their ability to plan, monitor, and evaluate learning processes. Similarly, Kim and Lim (2019) found that scaffolded learning environments increase students' engagement with complex learning tasks by encouraging deeper reflection and active regulation of cognitive processes. These findings reinforce the position that scaffolded instructional strategies are effective in promoting metacognitive development, particularly within STEM-related learning contexts.

The effect size obtained from the analysis ($\eta^2 = .072$) indicates a small but meaningful effect of scaffolded metacognitive activities on students' metacognitive awareness and self-regulation. This suggests that while the intervention had a statistically significant influence, the proportion of variance explained by the treatment is relatively limited. This implies that scaffolded metacognitive activities contribute positively to students' metacognitive development, but their effectiveness may be strengthened when combined with other instructional and contextual factors within the learning environment. This finding aligns with Dignath and Veenman (2021), who noted that instructional support in metacognitive strategies and scaffolding practices can lead to improvements in self-regulation and learning outcomes. It is also consistent with Mamun (2022), who emphasized that scaffolding enhances reflection, engagement, and self-regulated learning, particularly in structured learning environments.

Interestingly, the findings also showed that students in the control group recorded some improvement in metacognitive awareness and self-regulation, although at a lower level compared to the experimental group. This suggests that even conventional teaching methods may provide limited opportunities for metacognitive development, especially when students are exposed to structured tasks, exercises, or continuous classroom interactions that require some level of reflection. This observation is in line with Perry et al. (2019), who noted that metacognitive skills can develop gradually within classroom environments even without explicit instructional interventions, particularly when teaching is systematic and consistent.

However, the stronger performance of the experimental group highlights the added value of explicit scaffolding in guiding students' thinking processes. The structured support provided through guided questioning, modelling, reflection prompts, and feedback likely contributed to students' improved ability to regulate their learning. Nevertheless, the magnitude of the effect suggests that metacognitive development is a gradual process that may require sustained instructional exposure over time. This is supported by Bocoș et al. (2024), who emphasized that long-term and well-structured interventions are more likely to produce sustained improvements in metacognitive skills.

Furthermore, the findings on the Feasibility of Integrating Scaffolded Metacognitive Activities indicate that there is moderate support for the integration of scaffolded metacognitive activities into the STEM curriculum. While a proportion of respondents recognized the potential benefits of these activities in enhancing students' learning outcomes, there were also concerns related to implementation conditions such as resource availability and instructional readiness. These mixed perceptions suggest that although the approach is seen as beneficial, its successful adoption may depend on the level of institutional support and preparedness of teachers and schools.

The differences in the perceptions of the various stakeholders align with the findings of Zackariasson (2020), who observed that the success of scaffolded instructional approaches is influenced by the willingness of both teachers and students to engage with new pedagogical methods. Similarly, Rahma et al. (2020) emphasized that instructional innovations are more effective when educators are adequately prepared and willing to adapt their teaching strategies. Grebing et al. (2023) further highlighted that teacher buy-in and institutional support are critical factors in

the successful implementation of educational interventions.

Overall, the findings of this study suggest that scaffolded metacognitive activities have a positive effect on students' metacognitive awareness and self-regulation in STEM learning. The results support the view that structured instructional support can enhance students' ability to think about their thinking, regulate their learning processes, and engage more meaningfully with STEM content. However, the relatively small effect size indicates that scaffolded metacognitive activities should not be used in isolation but rather integrated with other supportive instructional strategies to maximize their impact on students' learning outcomes.

Conclusion

This research study has found that scaffolded metacognitive activities positively influence the metacognitive awareness and self-regulation of students in the STEM subjects significantly. The effectiveness of the scaffolded learning environment was confirmed by the fact that students who had gone through the scaffolded learning process showed high levels of metacognitive awareness and self-regulation. Moreover, the research finds out that it is possible to integrate scaffolded metacognitive strategy into the STEM curriculum, but it must be supported by adequate resources, teacher readiness, and curriculum alignment at the system level in order to be implemented successfully. The results of the study are consistent with the literature and highlight the value of scaffolding in the development of higher-order thinking and self-regulation

Recommendations

Recommendations are drawn based on the findings of this study as follows:

i. Osun State Ministry of Education is to strive to incorporate scaffolding activities in metacognitive activities in the secondary school curriculum in STEM subjects. This may be provided by revisiting the current curriculum and providing clear instructions on the application of these strategies to be used by teachers.
ii. Future research would be conducted to understand the long-term effects of scaffold metacognitive activities on STEM performance in students. Also, the same research could be performed in other parts of Nigeria as it would be possible to compare the findings and also have more generalized results.
iii. Teachers should be provided with workshops and other training programs to enable them implement metacognitive strategies effectively. Educators should know how to scaffold student learning, facilitate reflection and aid self-regulation.
iv. An adequate supply of resources, including technologies and materials that facilitate scaffolded learning should be given to schools. This may involve technology of reflection, formative assessment systems and problem solving technology.
v. Education policy makers and curriculum designers need to integrate scaffolded metacognitive activities in STEM education to support cognitive and metacognitive learning in learners. It is possible through formulation of uniform systems where scaffolded instruction is incorporated in the instructional approach.

Limitations of the Study

Although this study offers strong perspectives in the efficiency of scaffold metacognitive activities in STEM learning, it is important to mention that the research has a number of limitations. The results are carried out by using non-equivalent groups, which may limit their applicability. The randomized controlled trials may be possible to confirm the results in future research. The sample size of 120 students is quite small, which might fail to represent all the variation in the experience of students in Osun State and their results. It is suggested that larger-scale studies should be used to confirm the findings. It is possible that the scaffolded metacognitive activities might not have had their full impact due to a short period of the intervention. Better evaluation of the lasting impacts of these strategies could be undertaken in longer-term studies.

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