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Detective Learning of the Concepts of Acids, Bases and Salts in Physical Science by Ninth-grade Students using a Metacognitive Instructional Strategy: A Quasi-Experimental Study

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Efforts were made to verify the effect of metacognitive scaffolding as an instructional strategy on learning outcomes related to concepts of acids, bases, and salts for ninth-grade pupils in physical science. A quasi-experimental pretest-posttest design was employed. One hundred and seven (107) students from two government-sponsored schools chosen using a purposive sampling technique in the city of Kolkata, West Bengal, India, were sampled. For the experiment, 55 learners in the experimental group and 52 in the control group were selected. Only the experimental group of learners received treatment via metacognitive scaffolding. To obtain data, the researcher

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administered a self-developed and standardised criteria test (with a reliability coefficient of 0.86 and a validity of 0.93) and a reaction scale. For data analysis, one-way ANCOVA, percentiles, means, standard deviations, and coefficients of variation were applied. Results of the study demonstrated that the students who received treatment acquired better learning outcomes than the others. Furthermore, treatment recipients responded favourably to the use of metacognitive scaffolding when learning physical science.

Keywords: Metacognitive scaffolding; learning outcome; physical science; secondary level.

1. INTRODUCTION

The value of high-quality education and instruction is growing day by day across the world [1]. Very often, learners at the secondary level face difficulties in science subjects in general and physical science (i.e., physics and chemistry) in particular due to a lack of an appropriate learning environment [2]. Effective teaching methods as well as constant support and monitoring of teachers play a critical role in enhancing students' skills and competencies in terms of learning outcomes [3]. In the current Indian school scenario, the most difficult task for science teachers is to ensure quality teaching and learning in physical science to ninth grade students. Students in the ninth grade belong to the age group of 14–16 years. Their curiosity is to learn science through innovative approaches using demonstration, experimentation, hands-on learning, field work, etc. The overarching goal of the secondary science curriculum and pedagogy is to transform the education system away from the culture of memorization without understanding, which is prevalent at present, and toward actual understanding and learning how to learn [4,5]. Quality learning in physical science can be made possible by facilitating an appropriate learning environment for the learners. Most of the students have misconceptions about acids, bases, and salts at the secondary level as they are accustomed to acquiring knowledge directly from books and classroom lectures rather than from the field through taste, touch, and manipulation of materials available in their homes and neighbourhoods. According to the National Education Policy (NEP) 2020, a policy document published by the Indian Government, students at their schooling stage are far from experiential learning and suffer from science phobia [6]. Sustaining students' active involvement in the classroom, which in turn ensures quality learning in science, is another challenge for a science teacher that can be sorted out through the appropriate use of metacognitive teaching strategies. Using metacognitive strategies, students enjoy full autonomy to auto-regulate their learning process by employing their cognitive as well as metacognitive processes [7]. Students with metacognitive awareness know what they can and cannot do and what will help them get the knowledge or understanding they require. Students could describe appropriately how they managed their mental learning resources and what they did to improve their learning strategies [8].

One of the important strategies for teaching and learning science at the school stage is metacognitive scaffolding. According to research [9], metacognitive scaffolding had a favourable influence on students' design problem-solving processes. Further, from a research report, it is evident that in an e-learning environment in higher education, scaffolding improves metacognitive capacity, academic self-efficacy, and learning achievement. It also demonstrates that pupils with various cognitive types have similar learning outcomes [10]. Recently, the results of research work reported that incorporating metacognitive scaffolds into simulation-based inquiry learning in optics at the secondary level improved the development of skills involved in the process of science, particularly in complicated assignments [11]. Hence, based on the rationale, it is noticed that no study has been conducted anywhere to ensure competency-based learning as well as mastery learning outcomes in science in a detective manner using metacognitive scaffolding at the secondary level. As a result, the effectiveness of metacognitive scaffolding on learning outcomes for ninth-grade learners in the detective learning of acids, bases, and salts in physical science was investigated by examining their various properties such as taste, neutralization, identification, solubility in water, and indicator tests through their continuous involvement and monitoring process.

1.1 Conceptual Framework

1.1.1 Concept of metacognition

Initially, the term "metacognition" emerged from the works of American developmental psychologist John Flavell [12]. The term "metacognition" refers to higher-order thinking [13]. It helps to understand and regulate cognition. According to Schraw and Moshman's (1995) model of metacognition, the two broad components of metacognition are knowledge and regulation associated with metacognition [14,15]. Furthermore, knowledge associated with metacognition is subdivided into three categories: knowledge related to the person variable, knowledge related to the task variable, and knowledge related to the strategy variable. On the other hand, regulation associated with metacognition has been classified into four sub-categories, viz., planning, monitoring, evaluating, and revising [9].

1.1.2 Metacognitive interventions in classroom instruction

It is well known that the use of systematic and meaningful strategies leads to better learning outcomes. One promising way in which physical science can be learned meaningfully is through metacognition. One can argue that metacognition is likely to facilitate the process of teaching and learning in a multidirectional way because it encourages students to become aware of their thinking process. We must ensure that science teachers are equipped with metacognitive strategies in order to make science teaching and learning interesting and enjoyable for students. The roles of both teachers and students are equally important in executing metacognitive interventions in classroom instruction. The teacher helps in identifying the learning gaps of the students, provides suitable facilities, and assists in every stage of their learning. Metacognitive interventions are multifunctional in nature, and they can be applied to ensure competency as well as quality learning. Research studies have identified various metacognitive interventions for the improvement of quality learning [16-18]. Some of these strategies or interventions are briefly discussed in Fig. 1.

1. **Thinking aloud -** an instructional technique in which students express their thoughts or feelings as they work on a learning task or assignment. It is used by teachers and learners to promote metacognitive awareness.
2. **Concept mapping** - an innovative instructional technique applied by the teacher to present the content knowledge of the subject in pictorial forms like graphs, maps, flow charts, tree diagrams, van diagrams, etc. It helps in developing critical thinking, creativity, and meta-memory toward the connectivity between concepts and sub-concepts.

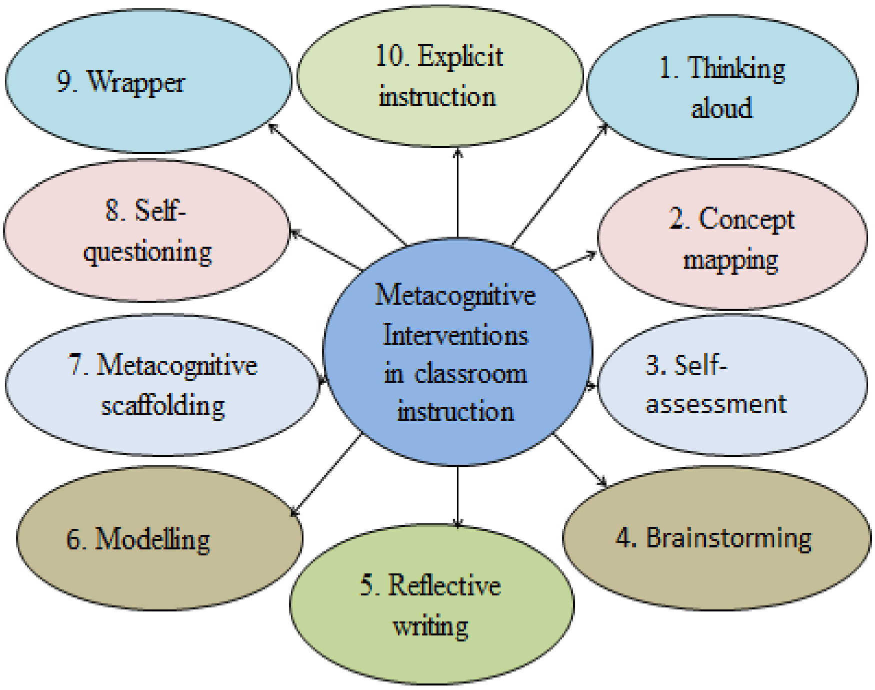

Fig. 1. Metacognitive interventions in classroom instruction

3. **Self-assessment -** an auto-monitoring technique used by learners to observe and evaluate their own progress and shortcomings while learning.
4. **Brainstorming -** a teaching-learning strategy in which students in small groups discuss an issue, share their perspectives, and learn concepts in cooperative and collaborative ways.
5. **Reflective writing** - an effective instructional strategy where the learners freely share their experience about a particular issue, concept, or event in the form of a written document.
6. **Modeling** - an instructional technique through which learners are actively engaged in learning and acquire new concepts presented by the teacher.
7. **Metacognitive scaffolding** - an important instructional strategy, has a close link with the constructivist approach to teaching, where the students get desired assistance from the teacher in completing a task.
8. **Self-questioning** - an auto-learning approach where students are inspired to ask themselves questions and assess their own progress and deficiencies in learning. This strategy helps promote the learners' self-regulated learning skills.
9. **Wrapper- This** strategy is concerned with the auto-monitoring behaviour of the learners in the classroom. It is generally used in the written examination, where examinees are inspired to think critically about the responses given in their answer scripts.
10. **Explicit instruction** - a new instructional strategy where the teachers apply appropriate steps in the teaching-learning process, like a demonstration, modeling, illustration, etc., keeping in mind the psychological development of the learners.

Hence, it can be said that metacognitive strategies facilitate a conceptual understanding of how to learn effectively. Students get the most benefit from grappling with exciting, relevant problems that might spark debate about alternative approaches to solving them [19,20].

1.1.3 Metacognitive scaffolding

A technique called "comprehension teaching," which is sometimes known as "scaffolding" includes providing pupils with temporary assistance until they are able to complete tasks on their own. It implies that teachers use scaffolding so that learners can perform the task appropriately. In other words, it is one of the metacognitive instructional strategies that refers to help given to students by teachers, competent classmates, or technological support in solving problems, completing assignments, or performing tasks that they would be unable to complete independently [21,22]. Scaffolding has been further subdivided into four categories [23], which are represented in Fig. 2.

In Fig. 2, the conceptual scaffold helps learners work through difficult problems. The metacognitive scaffold provides facilities for planning, monitoring, and evaluation. Procedural scaffolding places an emphasis on using available learning resources. The strategic scaffold suggests how to deal with tasks as well as problems. Previous research revealed that metacognitive scaffolding significantly aids students in acquiring subject-matter concepts [24].

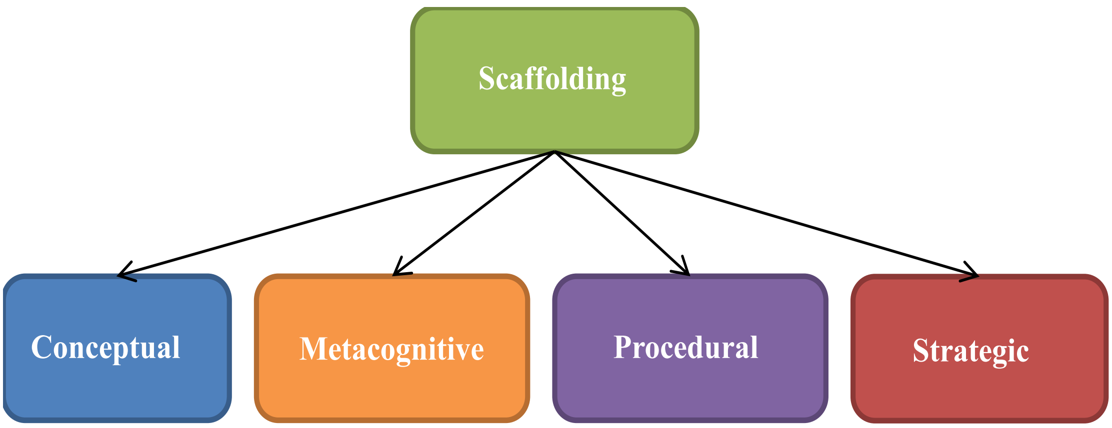

Fig. 2. Classification of scaffolding

2. LITERATURE REVIEW

Metacognitive thinking-aloud and self-assessment utilised in chemistry at the secondary level could significantly improve the performance of students [18]. There are positive and significant associations between metacognitive ability and learning in science subjects at the secondary level [25]. Studies have shown that scaffolding can help students improve their higher-order thinking skills [26]. Previouss studies demonstrated that metacognitive scaffolding improves academic performance and problem-solving [27-29]. From the literature, it can be noted that a very limited number of studies have been conducted on the use of metacognitive scaffolding in teaching science at the secondary level. Still, there is a significant gap in research studies examining the effect of metacognitive scaffolding in teaching and learning science processes at the secondary level through a detective approach to handling readily available materials at their homes and in their communities. Hence, from the related literature, it is emerged that no research conducted in India or abroad on verifying the effectiveness of metacognitive scaffolding on learning outcomes at the secondary level. So, while using metacognitive scaffolding as a strategy, it is easier to complete the task in the physical science of class IX students, where physical science begins as a separate subject in their curriculum at the West Bengal Board of Secondary Education (WBBSE) in Kolkata City, India. Class IX is a critical period for every student in terms of deciding whether to pursue a career in Science, Commerce, or Humanities in their higher education.

2.1 Present Study

In this study, efforts have been made to ascertain whether or not metacognitive scaffolding has a beneficial or detrimental impact on pupils' learning outcomes and how they reacted to the use of metacognitive scaffolding as an instructional strategy in physical science with students in the ninth grade.

2.2 Objectives

i. To compare the adjusted mean scores of learning outcomes in physical science of students taught using metacognitive scaffolding and the conventional method, using pre-learning outcomes as a covariate.
ii. To study the reaction of experimental group students to the use of metacognitive strategies in physical science learning.

2.3 Hypothesis

i. There is no significant difference in the adjusted mean scores of learning outcomes in physical science of students taught using metacognitive scaffolding and the conventional method, using pre-learning outcomes as a covariate.

3. METHODS

3.1 Experimental Design

A pretest-posttest control group quasi-experimental design was applied in this study. Metacognitive scaffolding is the independent variable, and learning outcome is the dependent variable.

3.2 Population

All class IX learners in Kolkata City, West Bengal, India, from various government-sponsored schools were treated as a population.

3.3 Sample and Sampling Technique

The sample for the study was selected through a purposive sampling procedure from one hundred and sixty-one (161) Hindi-medium schools in Kolkata City, West Bengal, India. One hundred seven students from class IX in the year 2022 from two government-sponsored co-educational Hindi medium schools in Kolkata City, West Bengal, were taken as a sample for this study. A description of the sample has been given in Table 1.

From Table 1, it is evident that the students of Arya Parishad Vidyalaya were randomly selected as the experimental group and those of Bharti Shiksha Sadan as the control group for experimentation.

3.4 Instructional Tools

Learning designs prepared for teaching different sub-units of acids, bases, and salts using a metacognitive scaffolding strategy were validated with the help of three subject experts by incorporating their valuable comments and suggestions before implementation.

Table 1. Description of sample

Sl. No.	School	Group	Gender		Total
			Male	Female	
1.	Arya Parishad Vidyalaya	Experimental	25	30	55
2.	Bharti Shiksha Sadan	Control	22	30	52
		Total	47	60	107

3.5 Experimentation

The procedure for carrying out the experiment has been represented in the following three phases.

3.5.1 Pre-experimental phase

Official permission from the two school authorities was sought by the investigators. Both groups were put through a test comprising 20 multiple-choice items with four options and one mark for each item to see if their understanding of acids, bases, and salts was compatible. The reliability coefficient was estimated using the split-half method and was found to be 0.86. The validity of the said test was also calculated and found to be 0.93. So the test was reliable and valid. Both groups were pretested first.

3.5.2 Experimental phase

After the pretest, the two groups were taught using two different methods of instruction. A metacognitive scaffolding was used with the experimental group, while a conventional lecture method was used with the control group. The researcher created a conducive learning environment to encourage the learners to actively participate and interact with one another. It was common in the traditional group to use a blackboard and charts as well as ask students questions in between lectures to convey information about the topic. Experiments were carried out for a period of ten weeks at one hour per day in each school on working days.

3.5.3 Post-experimental phase

Following the intervention, the same set of questions was employed to administer a posttest to both groups using the same sample of participants. The effectiveness of metacognitive scaffolding in terms of learning outcomes in physical science was evaluated by comparing the mean scores of learners in both groups.

Students acquired experiential learning joyfully and efficiently using the detective learning approach by receiving desirable assistance from the teacher (here, the investigator). The role of the teacher during the activities was that of a facilitator and guide, and he created an attractive learning environment in the classroom to ensure quality learning in physical science. Activities were self-performed by the students of the experimental group in the classroom with necessary assistance from the teacher; very few of these have been given in Fig. 3.

Fig. 3. Experimental group students learning the concept of acids, bases, and salts by verifying (a) taste and (b) indicator tests

3.6 Tools used for Data Collection

A self-developed and standardised competency-based test for assessing the learning outcomes, consisting of 25 multiple-choice items with one mark for each correct response and zero mark for each wrong response, and a self-developed reaction scale with a five-point rating scale were administered for collecting the data in this study.

3.7 Techniques used for Data Analysis

The Statistical Package for Social Science (SPSS) (IBM "SPSS" Statistics, Version 21) was used to perform statistical techniques, namely two-way analysis of covariance (ANCOVA), percentiles, means, standard deviations, and coefficients of variation, and the results were interpreted accordingly.

4. RESULTS

4.1 The Effect of Treatment on Student Learning Achievement in Physical Science While using Pre-learning Outcome as a Covariate

Table 2 demonstrates the computed value of one-way analysis of covariance (ANCOVA) for the first objective, which was used to analyse the data and compare the adjusted mean scores of learning outcomes in physical science for students taught using treatment.

The adjusted F-Value is 10.3, as shown in Table 2, indicating statistical significance at the df = 1 /104 level of 0.01. It demonstrates that there is a significant difference in adjusted mean scores of learning outcomes between students taught using metacognitive scaffolding and the conventional lecture method when pre-learning outcomes are considered as a covariate. The null hypothesis that there is no significant difference in the adjusted mean scores of learning outcomes in physical science between students taught using metacognitive scaffolding and the conventional method when pre-learning outcome is considered as a covariate is rejected. Moreover, from Table 2, the value of the effect size for the treatment is 0.09, which is significant at the 0.01 level, which in turn signifies that 9% of variances can be explained by the independent variable.

4.2 Reactions of Students towards the use of Metacognitive Scaffolding

The second objective was to study the reaction of experimental group students to the use of metacognitive strategies in physical science learning. The effect of metacognitive scaffolding on the learning outcomes of students in physical science was assessed by administering a competency-based posttest developed and standardised by the researcher himself. The data was analysed using SPSS by computing percentiles, the mean (M), standard deviation (SD), and the coefficient of variation (CV), which are presented in Table 3.

From Table 3, it is observed that, say, P_{50} = 21.4, means that below a score of 21.4, there are 50% of the pupils in the group. Therefore, it can be said that when the students are taught using metacognitive scaffolding, their learning outcomes are effective.

To understand the reaction of experimental group learners towards the use of metacognitive scaffolding in the teaching and learning of physical science, a 5-point scale comprised of 20 statements (10 positive and 10 negative) was developed and administered by the researcher. On a five-point scale, participants rated each statement on how strongly they agreed, disagreed, disagreed with, or agreed with it on various aspects of metacognitive strategies (planning, monitoring, and evaluation). Students were given a scale to read carefully and select one of the five options against each statement. Students were given ample opportunity to respond to questions without fear of reprisal. Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), and Strongly Disagree (SD) each received a weightage of 5, 4, 3, 2, and 1 for positive remarks. However, for negative statements, SA, A, U, D, and SD received a weightage of 1, 2, 3, 4, and 5, respectively. The results range from 20 to 100. For different categories, the percentage of responses statement-wise is presented in Table 4.

Table 2. Results of a one-way ANCOVA for the study of students' physical science learning outcomes using pre-learning outcome as a covariate

Source of Variance	df	$SS_{Y.X}$	M $SS_{Y.X}$	$F_{Y.X}$-- Value	Remark	Effect size (η_p^2)
Treatment	1	69.81	69.81	10.3	p < 0.01	0.09
Error	104	704.93	6.78			
Total	106					

Table 3. Summary of the percentiles (P), mean (M), standard deviation (SD), and coefficient of variation (CV) for the experimental group's posttest

Sl. No.	Percentiles	Learning outcome posttest scores for experimental group students
1.	P_{10}	16.00
2.	P_{20}	18.00
3.	P_{25}	18.00
4.	P_{30}	19.00
5.	P_{40}	21.00
6.	P_{50}	21.40
7.	P_{60}	22.00
8.	P_{70}	22.00
9.	P_{75}	23.00
10.	P_{80}	23.00
11.	P_{90}	24.00
12.	M	20.64
13.	SD	2.70
14.	CV	14.0%

Table 4. Statement-wise percentage of responses of students in the experimental group

Sl. No.	Statements	SA	A	U	D	SD
1.	The equipment used during the teaching-learning process was not appropriate.	0.0	0.0	18.2	18.2	63.7
2.	Demonstration speed was proper.	45.5	27.3	9.1	9.1	9.1
3.	The speed of teaching-learning was proper for all learners.	54.6	18.2	9.1	9.1	9.1
4.	The medium of instruction should not be Hindi.	9.1	9.1	9.1	27.3	36.4
5.	The voice of the demonstrator was clear.	54.6	27.3	9.1	9.1	9.1
6.	The content covered was appropriate.	36.4	27.3	9.1	18.2	9.1
7.	There is stimulus variation during the teaching-learning process.	27.2	45.5	9.1	9.1	9.1
8.	The repetition of data collection during the demonstration is not desirable.	9.1	9.1	9.1	27.3	45.5
9.	Teacher support was helpful during the demonstration.	36.4	27.3	18.2	9.1	9.1
10.	Learning through demonstration did not provide an effective learning outcome.	0.0	9.1	9.1	27.3	54.5
11.	Examples were given from real life,	36.4	36.4	9.1	9.1	9.1
12.	The teacher had not given a sufficient number of examples.	0.0	9.1	9.1	27.3	54.6
13.	Blackboard work was appropriate.	45.5	36.4.	9.1	9.1	0.0
14.	Probing questions have been asked during the teaching-learning was helpful for building the concepts.	54.6	18.2	9.1	9.1	9.1
15.	The question asked during teaching by the students was not encouraged by the teacher.	9.1	18.2	9.1	27.3	36.4
16.	Peer group interaction during the demonstration helped in quality learning.	27.3	36.4	18.2	9.1	9.1
17.	The presence of a teacher during the demonstration is not beneficial for learning.	9.1	9.1	18.2	27.3	36.4
18.	Students' involvement in carrying out the activities did not help in learning.	0	9.1	0	54.6	36.4
19.	There is no need to consolidate the main points.	36.4	27.3	9.1	18.2	9.1
20.	Situation based questions asked after the completions of class were not appropriate for evaluation.	0	9.1	18.2	18.2	45.5

From Table 4, it can be seen that out of 20 statements, 10 are positive (Sl. No. : 2, 3, 5, 6, 7, 9, 11, 13, 14, and 16), and the remaining 10 are negative (Sl. No. : 1, 4, 8, 10, 12, 15, 17, 18, 19, and 20). About 82% of students supported the idea that the equipment used during the teaching and learning process was appropriate. 72.84% of learners agreed with the rate of speed of the demonstration. 63.7% supported Hindi as the medium of instruction because it was more comfortable and understood in their home language. The maximum percentage of students opined that the voice of the demonstrator was clear, the content coverage was appropriate, stimulus variation was appropriate during the teaching-learning process, teacher support was helpful during the demonstration, examples discussed in the classroom were given from real life, and blackboard work was appropriate. Probing questions asked during the teaching-learning process were very helpful for building concepts, according to 72.8% of students. About 64% of learners opined that peer group interaction during the demonstration helped in quality learning. 91% of students supported their involvement in carrying out the activities that helped in acquiring effective learning. 63.7% of learners understood the need to consolidate the main points once again at the end of the class. 63.4 percent of learners disagreed that the situation-based questions asked after the completion of the class were not appropriate for evaluation. Hence, keeping in view the above findings, it can be concluded that most of the learners responded favourably to the use of metacognitive scaffolding in acquainting themselves with various concepts of physical science.

5. DISCUSSION AND LIMITATIONS

5.1 Discussion

The first objective was to compare the adjusted mean scores of learning outcomes in physical science for students taught through two different methods, with pre-learning outcomes considered as a covariate. Results indicated that students' learning outcomes were significantly higher in metacognitive scaffolding than in the conventional method, which is consistent with the findings of earlier studies [10,11,30-32], who found that students learn more when teachers employ metacognitive scaffolding in their lessons in science at the secondary level and that it is more effective than the conventional method. The second objective was to study the reaction of experimental group students to the use of metacognitive scaffolding as an instructional strategy in physical science. The students who received treatment reported that the items on the reaction scale helped them a lot in evaluating their strengths and weaknesses in learning. The findings demonstrated that most of the students responded favourably to the use of metacognitive scaffolding in acquainting themselves with various concepts of physical science in class IX. Moreover, studies that also support the above findings [27-29]. The findings of the current study thus demonstrate that students who use metacognitive strategies in learning can self-evaluate their understanding of the subject matter and also apply more effort to regulate their learning process effectively. The results are consistent with the earlier research [9,33]. Metacognitive scaffolding, when employed as an instructional strategy, results in signinificant improvements in the quality of learning [24,34].

5.2 Limitations

This research work was delimited to (i) class IX students (ii) physical science (iii) a short treatment period, i.e., ten weeks at the rate of one hour daily on working days in both schools (iv) Hindi Medium schools recognised by WBBSE (v) government-sponsored schools of Kolkata City, India, were used for experimentation. On the other hand, there are many limitations. The effect of treatment on cognitive load could not be verified. Researchers could not test the effects of other metacognitive strategies, namely thinking aloud, concept mapping, self-assessment, brainstorming, reflective writing, modeling, metacognitive scaffolding, self-questioning, wrappers, explicit instruction, etc., on academic performance and problem-solving skills.

6. CONCLUSION

Using a quasi-experimental research, the effect of metacognitive scaffolding on learning outcomes was examined as a factor in how well students in physical science in class IX performed and how they felt as a result of receiving treatment. According to the findings, metacognition scaffolding made a significant improvement in how effectively students learned various concepts of acids, bases, and salts. This strategy has been found to help students learn content more deeply. Most of the students reacted in favour of using metacognitive scaffolding in learning the concepts of physical science. Hence, this study's findings established that the learners who attended the treatment intervention acquired a higher level of creative thinking abilities and experiential learning with lifelong effects.

7. EDUCATIONAL IMPLICATIONS AND FUTURE PROSPECT

According to the findings of this study, metacognitive scaffolding was shown to be the most crucial indicator of enhancing students' learning, but students rarely use this strategy unless they are encouraged to do so. It's also the responsibility of teachers to ensure that their students have the tools they need to learn and develop their own metacognitive abilities. Hence, the current study makes the final observation that metacognitive scaffolding, if effectively applied by teachers in the context of teaching science subjects such as physical science (physics and chemistry) at the secondary level, could significantly improve student performance. Research on the remaining dimensions of metacognitive strategies, namely, thinking aloud, concept mapping, self-assessment, brainstorming, reflective writing, modeling, metacognitive scaffolding, self-questioning, wrappers, explicit instruction, etc., might be conducted for solving a variety of problems in different settings.

CONSENT

Consent to participate in the study and the results to be published were taken from the students' legal guardians.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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