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Development of Senior Secondary School Students' Metacognition in Physics in Bauchi State Using an Intervention Model

S. A. Mohammed, S. M. Bala and S. I. Muhammad
Department of Science Education, Abubakar Tafawa Balewa University, Bauchi
E-mails: Smabubakar2@atbu.edu.ng, smbala@atbu.edu.ng
ismuhammad@atbu.edu.ng

Abstract
The main aim of this study was to explore the development of senior secondary school students' metacognition in geometrical optics using an explicit metacognition intervention model for problem-solving. A quantitative research method that involves a Cohort longitudinal design was adopted. Modified random sampling technique was used to select 13 students within the ability levels of high, medium and low students from a population of 156 SSII students in Bauchi Metropolis. Three series of intervention were used as the treatment which lasted for six weeks. Geometrical Optics Metacognitive Ability test (GOMAT) was used for the administration of pretest, test 1, test 2 and test 3. Findings from the knowledge growth line graph and repeated measures ANCOVA showed that there was a significant shift/improvement in the knowledge growth and knowledge gain of senior secondary school students in geometrical optics. The knowledge growth of students was moved from its initial status of weak to that of excellent metacognition. This finding further concretizes the findings of earlier studies on the importance and significant role of metacognition in physics learning. The study recommends for the conduct of this study on a larger sample of high, medium and low students in order to find out the trajectory of knowledge growth in metacognition between students from these groups and also find out how suitable the intervention model is in terms of gender.
***Keywords**: Metacognition, Knowledge Growth, Knowledge Gain, Intervention Model.*

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I. Introduction

Higher-order cognitive skills, such as ability to elaborate, synthesize, analyzed, apply, and evaluate specific learning information are very essential for students to achieve academic success and adjustment in life. With the increasing demand of an ever changing and challenging problem-ridden world, the least any learner ought to acquire from school is the ability to utilize an efficient thinking and problem-solving abilities to face the complex situation and challenges of everyday life. Metacognition is a higher-order thinking skill that serves as the operating mechanism of learning and consists of two main components: metacognitive knowledge and metacognitive regulatory skills (Sattin *et al*., 2021).

Student's lack of metacognition towards learning physics causes several learning problems such as lack of interest, competency, thinking as well as problem-solving skills (Tang, 2020). The use of teacher-centered methods has affected students' thinking ability and made them in active by just memorizing the learned content for examination purpose. Gengle, *et al*. (2017) maintained that, promoting student metacognition is generally suggested to be part of the recommendations for improving the declining performance in science at secondary level public examinations. Several studies reported that students with good metacognition demonstrate good academic achievement compared to students with poor metacognition, they consider metacognition as a strong predictor of academic success (Goupil, & Kouider, 2019; Kavousi, *et al.*, 2019; Tang, 2020). Halpern and Dunn, (2021; 2022) also showed that students with high academic achievement demonstrate high metacognition. However, studies on metacognition in the process of learning physics in Nigeria was found to be limited must especially at secondary school level being the foundation of physics education (Ajaja & Agboro-Eravwoke, 2017). Based on this therefore the need for more studies to be carried out on the development of metacognition (as a psychological construct) to improve students' self-reliance, decision making, critical thinking and problem-solving skills in physics.

Also the growing emphasis focusing on student/learner-centered teaching at various educational levels has led to recommendations for increased use of teaching methods that encourage metacognition (Kohen & Kramarski, 2018). Furthermore, teaching methods that promotes metacognition are value-added strategies that encourage students to reflect on the basis and the process of their learning experiences in addition to the norm of solving problems and engagement in learning (Avargil, *et al.*, 2018). Basically, metacognition focused on the active participation of an individual in his or her learning process by knowing how to process and use knowledge directly applicable to real-life scenarios. Therefore, this study intends to develop senior secondary school physics students' metacognition in Bauchi state using an intervention model that is learner-centred.

II. Statement of the Problem

Evidence such as Diaz, (2015) and Desoete, (2019) suggests that classroom instruction has continuously relied upon conventional methods of teaching, making students to become passive recipients of information rather than being active and also instill phobia. Such phobia affects students' metacognition that may results in students engaging in many horrible practices that include examination malpractice (Mohammed, 2020). Teacher-centered approach encourages memorization of facts and students may not acquire reflective thinking skills which also affects their interest in the subject. Participating actively and independently in learning process boost students' interest towards what is to be learnt and motivate them to ask several questions that will help them to solve problems. According to Mohammed (2020) promoting metacognition has been suggested as an important means for enhancing learner's competency, interest and problem-solving skills. Problem-solving skills proved to be a mediating variable between metacognition and achievement (Drigas & Mitsea, 2021).

Researchers such as Azevedo (2020); Shekhar and Rahnev, (2021); Halpern and Dunn (2021; 2022) showed that metacognition was a direct predictor of learning achievement. Consequently, this research is motivated by the findings of these forgone studies and the growing incidence of failure in physics in public examinations such as WAEC and NECO senior school certificate examinations (SSCE) in Nigeria which was a clear manifestation of students' inability to solve problems (WAEC Chief Examiners Report, 2021). It was thought, that students' inability to solve problems may be due to poor metacognition. That is, they lack the capacity to freely think and evaluate their thinking while solving physics problem during examination. Table 1, represent the summary of percentage of students that were able to pass SSCE with distinction and credit from 2020 to 2023.

Table 1: Summary of Physics Students that Registered for SSCE and percentage passed in Bauchi from 2018 -2020

S/N	Year	No. of Candidates That Registered	Percentage Passed with Credit and Distinction
1	2020	728,924	14.2%
2	2021	762,340	13. 8%
3	2023	814,546	15.4%

Source: Bauchi State Ministry of Education, 2024

Therefore, developing secondary school students' metacognition may pave the way to improve their interest, competency, critical thinking, problem-solving ability and academic achievement in physics.

III. Literature Review

Metacognition as a construct has evolved over the years from when it was originally defined as 'Thinking about thinking' by (Flavell, 1979). Furthermore, metacognition was originally believed to be comprised of conscious actions (Flavell, 1979). There were two main components of metacognition known as metacognitive knowledge (MK) and metacognitive regulation. The component of MK includes the beliefs and thoughts that an individual has about their own or another individual's cognitive processes and have three sub-components; declarative, procedural and conditional knowledge (Flavell, 1979). Metacognitive regulation [also known as metacognitive skills (MS)] is a more active component that includes the process of monitoring, controlling, and evaluating learning outcomes (Efklides, 2006). Students' metacognition can also be seen from the students' ability to solve any problems faced in everyday life.

Developing metacognition requires encouraging students to ask themselves questions in order to enable them stimulate their thinking processes and control their thoughts. Guiding and encouraging students in asking appropriate questions activates their metacognition (Azevedo, 2020). Most especially questions such as 'What is next?', 'What will I think of?', 'Why do I think so?' and 'How can I prove this?' triggers their thinking and contribute to the development of metacognition (Kuzle, 2013). From this point of view, metacognition is essential for a successful learning because it enables the individuals to direct their own cognitive skills towards higher level. Metacognition starts with awareness and increases in accordance with the academic success. Several researchers have examined how metacognition relates to various measures of independent, initiative thinking in learning process and problem-solving.

Studies such as Zepeda et al. (2019); Shea and Frith (2019); Willison et al. (2020); Youngerman et al. (2021) on learning and problem-solving in science education found that it is pertinent to integrative learning, crucial for problem-solving, involving an 'extensive entanglement between metacognition and manipulation in working memory. The studies that were conducted in both primary, secondary and tertiary institutions, includes primary school Mathematics classrooms where the metacognitive talk was stronger versus those where it was weaker (Smith & Mancy, 2018); secondary school Physics, where student metacognition measures correlated with higher levels of performance (Gonzalez et al., 2017); and Chemistry classes for those in initial teacher education (Adadan, 2020). After inquiry-based instruction, participants with high-level metacognitive knowledge, when compared to participants with low-level metacognitive knowledge, were more likely to change their non-scientific conceptions of lunar phases to science-oriented ones (Gonzalez et al., 2017). Additionally, the participants with high-level metacognitive knowledge developed a more coherent and consistent understanding of gas behaviour, and retained their scientific understanding months after instruction (Gonzalez et al., 2017).

Metacognition, which means thinking about thinking, generally covers various skills that are inter-related to thinking and learning, which are critical thinking, reflective thinking, problem-solving and making a decision. Individuals, who have more developed metacognitive skills, are also better problem solvers, decision makers and critical thinkers which is the focus of the present study.

Objectives of the Study

The study was guided by the following objectives;

a. Capture and document the pattern of senior secondary school students' implementation of the metacognitive knowledge and metacognitive regulatory skills while solving the physics problem before after the intervention.

b. Find out senior secondary school students' knowledge gain before and after intervention

Research Questions

Based on the above objectives, the following questions will be answered

a. What is the pattern and level of senior secondary school students' implementation of the metacognitive knowledge and metacognitive regulatory skills while solving the physics problems during the intervention?

b. What is the knowledge gain of senior secondary school students before and after the intervention?

Research Hypothesis

The following research hypothesis were tested at 0.05 level of significance

a. There is no significant difference between senior secondary school students' knowledge gain before and after intervention.

IV. Methodology

a. Intervention Model

Two models were adapted for the purpose of this study, Flavell (1979) metacognition model and Heller and Heller (1995) Explicit Problem-solving model. The reason for the adaption was to explicitly bring out all the constructs used in the intervention process. Flavell (1979) metacognition model is made up of two components namely; metacognitive knowledge (MK) and metacognitive regulation Skill (MS). The MK have three sub-components; declarative, procedural and conditional knowledge, while the metacognitive skills (MS) is a more active component that includes the processes of planning, monitoring, and evaluating learning outcomes. Heller and Heller (1995) Explicit Problem-solving model that comprises of six steps of problem solving namely; focus the problem, described the physics, plan the solution, execute the plan and evaluate the solution was also used to strengthened students problem-solving skills in the development of the metacognition. Execution and reflection used in place of monitoring in the modified metacognition model are fundamental constructs that are silent but highly significant in developing problem-solving abilities. Hence, Figure 1 represents the adapted Explicit Metacognition Model for problem-solving;

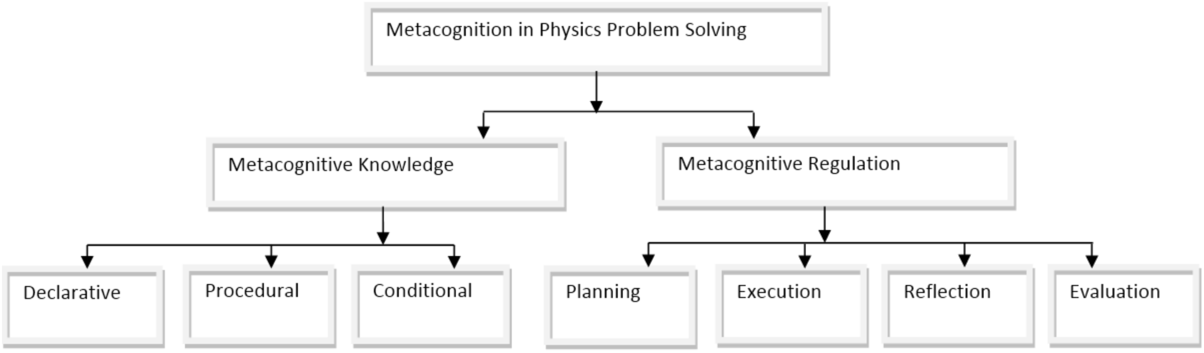


Figure 1: Explicit Metacognition Model for Problem-solving.

Based on the above model, teacher as a facilitator guides the students step by step as follows:

1. Declarative knowledge: Before solving the problem, read problem more than once, understand the problem, restate the problem and check the familiarity with similar problems.
2. Procedural knowledge: Identify the given information in the problem and consider different strategies of solving the problem.
3. Conditional knowledge: Detect and assess understanding of problem and strategies appropriateness for implementation.
4. Planning: Select appropriate strategy and cognitive resources for solving the problems. Execution: Putting the strategies into action step by step to solve the problem considering reasons for applying each step (i.e. explaining the thinking processes and the answer in writing).
5. Reflection: Check the solution step by step, the correctness of the calculation, reread the problem to control whether the solution was sensible and the thinking on different solution. Reassess the strategy appropriateness and decide whether to progress or change the strategy.
6. Evaluation: Assess result accuracy and sense. Anomalous result prompts an assessment of whether the solution is correct or meaningful.

b. Design, Sample and Instrumentation

Cohort longitudinal design was adopted to study a group of ten (13) SSII students in Bauchi state, selected using a pretest that measures their background knowledge of thinking and problem-solving. The sample of the study initially made up 15 students selected from the ranking of scores of 156 SSII students pretested using four essays, Geometrical Optics Metacognitive Ability Test (GOMAT) questions and categorized into three groups of high, medium and low. The study took a period of six weeks to track knowledge growth over a period of time using the adapted Explicit Metacognition Intervention Model for Problem-Solving (See Fig. 1). The sample was finally made up of 13 students due to withdrawal of two students from the intervention. Geometric optics being one of the difficult topics in physics was used for the study. The intervention was repeated three times with a post-test administered at predetermined interval of one week using four essay items. The reliability of Geometrical Optics Metacognitive Ability Test (GOMAT) was obtained using a pilot study and a value of 0.79 was obtained using Guttman Split half reliability making the instrument good and reliable for the conduct of the study. The questions in GOMAT were used through-out the study to track changes within the cohort. Geometrical Optics Metacognition Scoring Rubric (GOMSR) developed by the researchers using the modified model was used in scoring the student work. The data collected from the series of the intervention were analyzed using mean, Standard deviation, repeated measures Analysis of Covariance (ANCOVA) and Knowledge Growth Line Graph analysis.

V. Results and Discussion

The data collected from this study underwent data cleaning and preliminary checks were conducted to ensure there was no violation of the assumptions of normality, linearity, homogeneity of variances and homogeneity of regression slopes.The highest score for each item in GOMAT by scoring using the rubric is 21 which imply that the total score for the four items in GOMAT is 84. The highest score for each construct according to the rubric is 3. This implies that the total score for all the 13 students for each construct is 3x13 = 39. Therefore the whole 4 items in GOMAT, the total score for all the items for each construct will be 39x4 = 156. In order to clearly categorize the students' level of metacognition prior, during and after the intervention, the researchers used the following to describe the students' level of metacognitive skills (see table 2).

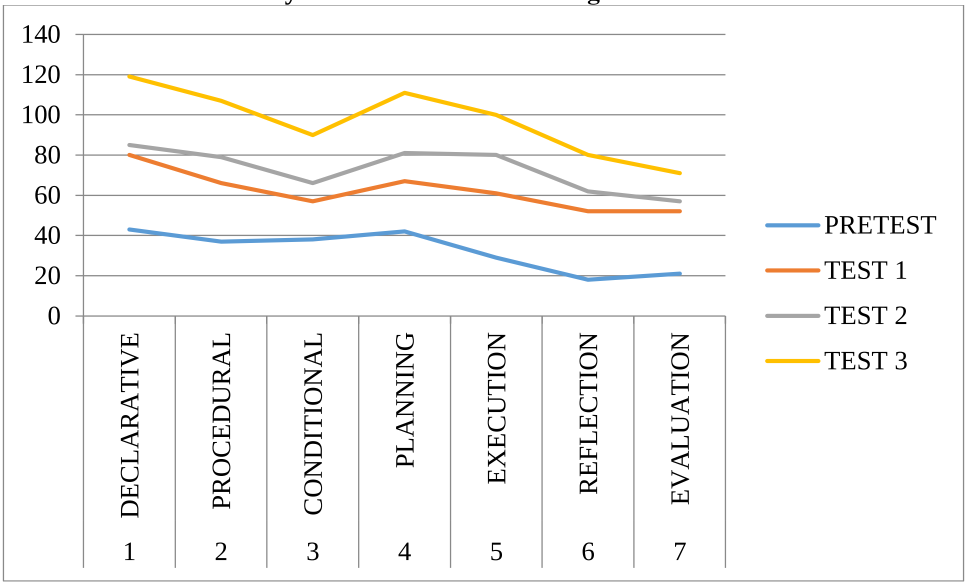
Table 2: Categorization and Description of Students Metacognitive Skills

SN	Interval	Interpretation/Description
1	Below 50	Weak
2	51 – 80	Moderate
3	81 – 110	Fair
4	Above 110	Strong

Research Question 1

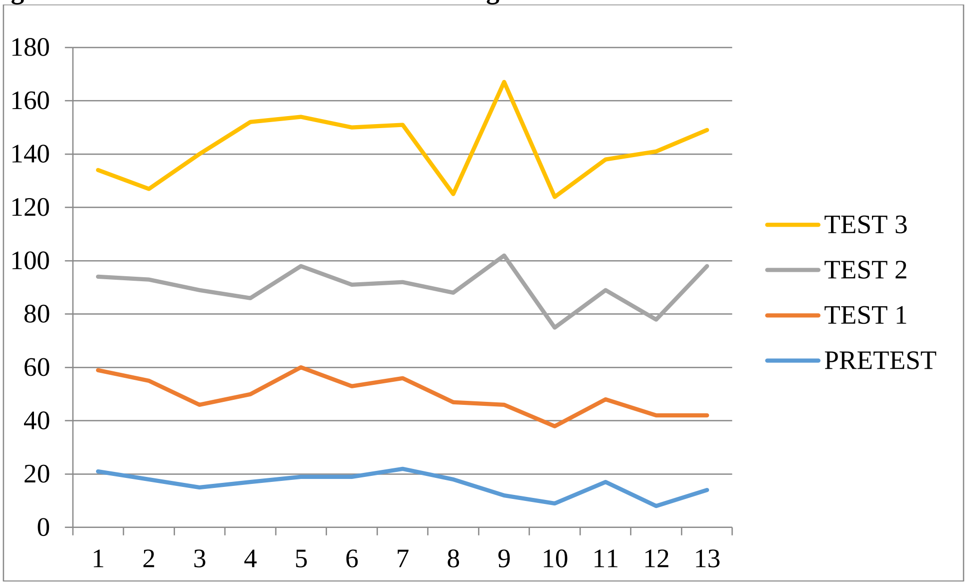
What is the pattern and level of senior secondary school students' implementation of the metacognitive knowledge and metacognitive regulatory skills while solving the physics problems during the intervention?

Fig 1: Pattern of Senior Secondary School Students' Metacognitive skill before and After Intervention



The data from the line graph shows the knowledge growth of senior secondary school students exposed to the focused intervention using explicit metacognition model. The data and results shows scores for each formative construct of metacognition across the different intervention phases. The formative constructs are: declarative, procedural, conditional, planning, execution, reflection, and evaluation. The scores for each construct generally increased from the pre-test to the final test 3, indicating an improvement in the knowledge growth of students within all the constructs over the course of the intervention. The construct with the highest growth across all tests is ***declarative***, suggesting a stronger focus or development in this area. The construct with the lowest growth across all tests is ***evaluation***, indicating a potential area for further improvement. Summarily, findings from the study reveals that senior secondary school students knowledge and metacognitive skills have been moved or enhanced from that of weak to being strong. The knowledge growth of students from the interventions reveals that the shift in students' knowledge growth was not the same (see fig. 2). Some students performed better than their counterparts.

Fig 2: Pattern of Individual Student Metacognitive skill before and After Interventions.



Students who appeared to have weak metacognition during the pretest (see no. 9) turned out to be one of the best student after the teaching intervention indicating that senior secondary school students knowledge growth can be enhanced from that of novice to that of experts if they are exposed to teaching intervention that incorporates the use of metacognitive and self regulatory skills.

Finally, findings from the study indicate that in ***Pretest:*** senior secondary students' metacognition across all the components and sub components was ***Weak*** prior to the intervention. Students exhibited weak metacognitive skills such as wrong conceptualization of the problem, wrong choice on the use of strategies, poor error analysis and poor reflection as a result of wrong connection between physics principles and mathematical physics equations. ***Test 1:*** The line graph also indicates that senior secondary students' metacognition across all the components and sub components was ***Moderate*** after the first intervention. ***Test 2:*** after the second intervention to address areas of difficulties from results of the first intervention, findings from the data as indicated in the line graph shows that senior secondary students' metacognition across all the components and sub components was ***Fair*** after the second intervention. ***Test 3:*** The line graph indicates that senior secondary students' metacognition across all the components and sub components was ***Strong*** after the third intervention.

Research Question 2

What is the knowledge gain of senior secondary school students before and after the intervention?

Table 3: Mean, Standard deviation and Mean gain of students for the interventions

Group (Explicit Metacognition Intervention Model)	N	Mean	SD	Mean Gain
Pretest	13	16.08	4.31	
				17.23
Test 1	13	33.31	3.79	
				6.46
Test 2	13	39.77	5.51	
				12.46
Test 3	13	52.23	10.46	

Result and findings from table 3 shows that the mean knowledge gain in metacognition of senior secondary school students exposed to the explicit metacognition intervention model for all the test is *M = 16.08, 33.31, 39.77* and *52.23* respectively. A mean gain of *17.23, 6.46* and *12.46* was established between the pretest and other test. The increase in the mean of students from the pretest, test 1, test 2 and test 3 and the mean gain between the tests indicates that the intervention has improved the metacognition of students. The standard deviation (*SD = 4.31, 3.79, 5.51* and *10.57*) indicates that some students showed higher gains than others across the group as indicated from the line graph.

Research Hypothesis
There is no significant difference between senior secondary school students' knowledge gain before and after intervention.

Table 4: Repeated Measures of Analysis of Co-Variance (ANCOVA) of Between Test Effect of Students Geometrical Optics Explicit Metacognition Intervention Model.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	5029.295	1	5029.295	84.626	.000	.885
PRETEST	36.533	1	36.533	.615	.450	.053
Error	653.723	11	59.429			

One way repeated measure ANCOVA was conducted to determine whether the mean gains after the three interventions are statistically significant to show whether the improvement can be confirmed to be only due to the effect of Explicit Metacognition Intervention Model in geometrical optics at pretest, test 1, test 2 and test 3. The mean and standard deviation are presented in table 3. Mauchy's test of sphericity was estimated to ensure there were no violations (p-value = 0.225 > 0.05). Results from the data analysis reveals that, F (1, 13) = 84.626, p = .000, partial eta squared = .885 indicating a large effect size. The null hypothesis was however rejected (p = .000 < 0.05) implying that there was a significant difference in the knowledge gain (scores) of senior secondary students taught geometrical optics using Explicit metacognition model.

Table 5: Post-hoc Test for Pretest, Test 1, Test 2 and Test 3 for Between Subject Effects of Students Taught Geometrical Optics Using Explicit Metacognition Intervention Model

(I) Metacognitive Model	(J) Metacognitive Model	Mean Difference (I-J)	Std. Error	Sig.b	95% Confidence Interval for Differenceb Lower Bound	Upper Bound
1	2	-6.462*	1.899	.018	-11.815	-1.108
	3	-18.923*	2.876	.000	-27.033	-10.813
2	1	6.462*	1.899	.018	1.108	11.815
	3	-12.462*	3.097	.006	-21.196	-3.728
3	1	18.923*	2.876	.000	10.813	27.033
	2	12.462*	3.097	.006	3.728	21.196

Post-hoc comparisons using Bonferroni test showed significant improvements in knowledge gain (scores) between pretest to test 3 at p < 0.05. This indicates that the knowledge gained from each intervention were significant. These findings further confirm the impact of the intervention and also the findings from the line graph.

VI. Discussions

This section of the study discusses the findings from the data analysis on the development of senior secondary school students' metacognition in physics problem solving using an explicit metacognition intervention model. This study was deemed necessary due the conduct and findings from a baseline study that affirmed the several issues that have been documented in physics education literature highlighting difficulties students encounter in understanding certain concepts related to geometrical optics. The concepts under geometrical optics covered by this study include Reflection and Refraction of light plane spherical and curved mirrors.

Correspondingly, research question one sought to investigate the pattern and level of senior secondary school students' implementation of the metacognitive knowledge and metacognitive regulatory skills while solving the physics problems during the intervention. Findings from the study revealed that senior secondary school students exposed to the explicit metacognition intervention model had significant shift and improvement in their knowledge growth before and after the intervention. The study further revealed that though there were significant shift/improvements in students' knowledge growth through the analysis of each of the formative constructs of the intervention model and the overall analysis of the students' metacognitive skills, the improvement was not the same for all the students. The knowledge growth improvement is not farfetched from the scientific inquiry and constructivist nature of the metacognition model. The overall metacognitive skills enabled students to develop high order and critical thinking skills needed for learning. This further shows and reveals that students with metacognitive skills understand what they read and it in turn helps them to better their learning outcomes (Aydem & Kubane, 2014; Ozturk et al., 2020; Salam et al., 2020; Tohir; 2019).

The findings of this study corroborates with findings of several studies on how students learning outcomes can be improved through metacognition and how students' possession of metacognitive skills positively affects their learning outcomes such as problem solving, academic achievement, knowledge gain, motivation attitude and academic self efficacy (Gonzalez et al., 2017; Adadan, 2020, Mohammed, 2020; Drigas & Mitsea, 2021; Azevedo, 2020; Shekhar & Rahnev, 2021).

The second research question of the study was to find out senior secondary school students knowledge gain before and after the intervention. This was done in order to establish statistical significance from the differences between the results for pretest, test 1, test 2 and test 3. This is imperative in order to confirm that the knowledge growth gained was due to the effectiveness of the explicit metacognition intervention model. Repeated measures ANCOVA results of the study, therefore, revealed that there was a significant mean difference in the knowledge gained by students from all the tests administered before, during and after the intervention. Therefore, it can be said that senior secondary school students' knowledge gain recorded was due to the effectiveness of the explicit intervention model for problem solving. The findings are consistent with that of Arsuk and Memnum (2020) and Kaplan et al., (2016) on the positive role of metacognition on students learning outcomes.

VII. Conclusions

From the finding of this study, it can be concluded that the use of explicit metacognition intervention model while learning helped students to understand physics concepts. When students are supported with metacognitive strategies of planning, monitoring, execution, reflection and evaluation, they benefited much in understanding of geometrical optics concepts and minimize misconceptions.

VIII. Recommendations

This study investigated the development of senior secondary school students' metacognition in physics problem solving using an explicit metacognition problem-solving model. The study can be replicated with more students at different level of Education. Since the sample of the study was drawn from a modified random selection of high, medium and low students, another study can be conducted to find out the trajectory of knowledge growth between students from these groups. It will also be nice to contribute empirically, whether the use of the model is gender friendly. Finally, the federal government through the ministry of Education should introduce explicitly, metacognitive skills as essential component of general science curricula.

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