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The Students' States of Matter Achievement: Reasoning Ability or Instructional approach?

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Abstract: *The present study is aimed to determine if there is any relationship between cognitive developmental level and states of matter achievement. A total of 39 Form Two students constitutes the sample of the study. The subjects were tested at a two-time interval (phase1, phase2). The study was conducted in two randomly selected government day secondary schools. Lawson Classroom Test of Scientific Reasoning (LCTSR) and States of Matter Achievement Test (SMAT) were administered to participants to gauge their cognitive level and states of matter achievement. One-way analysis of covariance (ANCOVA) was conducted to investigate the effect of cognitive level on students' states of matter transformation. The student's cognitive level is the independent variable (concrete and formal), the dependent variable is the multiple-choice test on states of matter transformation. Students' pre-test scores were used as a covariate. The result showed that while there is a mean different between concrete and formal students (concrete=51.45 and formal 54.59), however, there was no statistically significant effect of cognitive level on student states of matter achievement $F(1, 36)= 3.156$, $P>0.05$, also the covariate (pre-test) was not significantly related to participant's states of matter achievement $F(1, 36)= 0.90$, $p>.05$.*

Keywords: States of Matter Achievement, Cognitive level, 7E-Inquiry Integrated Module, Piaget Theory.

1.0 INTRODUCTION

Over the years research on students reasoning ability and its relation to achievement has been conducted (Cavallo, Rozman, Blickenstaff, & Walker, 2003; Han, 2013; Jones, Howe, & Rua, 2000; Karbach, Gottschling, Spengler, Hegewald, & Spinath, 2013; Lawson, Banks, & Logvin, 2007; Lawson & Thompson, 1988; Wang, Yuan, & Wang, 2020; Yenilmez, Sungur, & Tekkaya, 2006) these studies has received great attention in science education and instructional research. For instance, Yenilmez et al. (2006) researched the student's achievement in relation to reasoning ability or prior knowledge and gender. The author's finding revealed a significant difference between students at higher and law reasoning ability in terms of their achievement in favour of higher reasoners. The result also showed that reasoning ability is a strong predictor of achievement in photosynthesis and respiration in plants. Similar results were earlier reported by Cavallo (1996), who found reasoning ability as a strong predictor of student's achievement. Furthermore, Karbach et al. (2013) argue and conclude that cognitive ability is a strong predictor of early adolescent achievement. Regardless of how instructors conduct their instruction, the need for identifying individual difference is key ingredient for a successful accomplishment of instructional objectives. According to Kubat (2018), in teaching preparation, selecting a strategy focused on the student's individual style, and pace is likely to lead to a more effective learning atmosphere rather than employing collective instruction. The author further buttresses his argument by insisting that since not every individual learns the same way, teachers need to employ teaching methods and strategies that help students with different abilities and skills to learn while embedding appropriates activities that are within the cognitive level of the child. Even though several studies conducted, it is still an open question whether cognitive level predict states of matter achievement or not. In this study we hypothesized that cognitive level does not predict states of matter achievement. However, based on literature cognitive level is only an ingredient for teachers in their systematically preparing instruction.

2.0 DEVELOPMENTAL COGNITIVE LEVEL

Our understanding of the cognitive level is based on Piaget's cognitive theory. Piaget advocated for teachers to assess the individual level of learning to match their instruction. Piaget's first stage to identify cognitive growth is the Sensorimotor Stage (birthed two years old). At this stage, children will discover the connections between their bodies and the world. In the preoperational phase (age 2 through 4), a child responds to all stimuli as they are the same (Wadsworth, 1979). Children logically begin to think and organise thoughts accurately during concrete operations (age 7 - 11). The child does not need unique objects to create sound judgements in structured operations (beginning at ages 11 to 15). He or she can think logically and subjectively (Wadsworth, 1979).

A day when the child born marks the start of the sensory-motor stage, the mental development process starts. The sensory-motor stage has been widely described by Piaget to be during the first two years of life (Wadsworth, 1979). In the early year of birth, children only perform smaller reflex behaviour at the early stage; the infant only knows how some sensory feelings of pain or feeling hungry. The child at this period has developed the schema of ideas crying, eye movement, sucking and grasping. In the later period, the child develops mental development of language (Driver, Asoko, Leach, Scott, & Mortimer, 1994). At a sensory-motor stage the child is unaware of his environment; his or her mental development is basically reflexive.

When the child begins to move away from being reflexive to getting egocentric, which is well acknowledged by Piaget in his bid to explain mental development. At this period, the child has moved from the sensory motor to the preoperational stage of cognitive development. At this period, the child has learnt to suck his or her fingers, most commonly the thumb finger. At this stage, the child can respond to gestures, sound and moving objects. At this period, the child has developed personal way of seeing things. According to Piaget this stage is dominated by thumb-sucking, eye and head movement, responding to sound and visuals (Wadsworth, 1979). As the child grows in months (4-8), he or she has developed more awareness of objects, which signifies distinguishing self from other events beyond his body.

The preoperational stage (2-7 years) is characterised by language learning at this stage the child has start to understand his or her environment. At the age of two years or so the child begins to practice spoken words; the child begins with one-word practice on sentence and gradually expands to understanding what he or she hears. According to Wadsworth, (1979 p. 71):

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"Piaget (1926) suggest, on the basis of his observations of young children's conversations, that there are essentially two different classifications of preoperational child's speech:(1) egocentric speech, and (2) socialised speech. Egocentric speech is characterised by a lack of real communication; socialised speech on the other hand, is characterised by communication".

Ages 7 to 11 is characterised as a concrete developmental cognitive stage. At this stage, the reasoning of the child becomes logical, which Piaget refers to as a logical operation. In this developmental process, the accomplishment of concrete activity is cognitively the most significant. A child can carry out a logical task during this period. While this period is viewed as a transition period, the develops ability to classify objects, not egocentric as the child can now accept the view of others, can solve concrete problems (Wadsworth, 1979 p. 107).

The final stage of Piaget's theory is the formal operational phase. It starts at the age of 11 to 15 and continues during adulthood. The ability to shape and systematically test the hypotheses to respond to a problem characterises them. Research conducted by Higgins-Trenk and Oaite cited by Decano (2017), revealed that most of the adolescents and young adults showed formal operational thinking. The Formal stage of intellectual development starts at 11-12 years of age, and the individual becomes fully formal at age 15-16. There is experimental evidence that individual differences in cognitive development exist in a group of students at the same school grade and with a similar background (Kubat, 2018). Regarding this, adopting instruction that ensure equity and quality of skills and experience for the students is necessary. In this context teacher should create a rich learning atmosphere by drawing attention to the lesson, considering the individual differences of the students.

3.0 THE 7E-INQUIRY INTEGRATED MODULE CONCEPTUAL FRAMEWORK

According to Australian teachers and academics, there are five stages model for meaningful learning to occur. These include 1. Engagement; 2. Exploration; 3. Transformation; 4. Presentation; 5. Reflection (Pritchard, 2017). The Australian stakeholders place engagement at the beginning of learning, which agrees completely with the constructivism approach to teaching and learning and the adopted approach to this current study. One of the problems teachers faces is selecting an appropriate approach to teaching a certain kind of knowledge (Scoular, Eleftheriadou, Ramalingam, & Cloney, 2020). The 7E-Inquiry Integrated Module integrates multiple methods such as inquiry learning, game-based learning, and problem-solving learning approach with states of matter topic across the 7E learning cycle. This module is developed based on the Dick and Carey instructional design model and underpinned by the theory of constructivism. The Dick and Carey model has been effective and suitable in designing teaching and learning (Hartman, 2017; Perinpasingam & Balapumi, 2017).

The rationale for developing this module arose from the literature indicating the need for innovative teaching and learning different from the current approach of using textbooks and assignments (Ayodele, 2016; Idowu, 2011; Osuolale, 2014; Samuel, 2017). A module is defined as an individual, self-contained unit of a designed series of learning activities to help students achieve specific, well-defined goals (Guido, 2014). The module is an instructional learning series of activities well-coordinated that is relatively short and precise, with content arranged to achieve the learning objectives (Telaumbanua & Surya, 2017). This module was designed to assist students in understanding abstract concepts while making observations, measurement, classifying and predicting states of matter transformations. Scale Content Validation Index (S-CVI=0.81) from the opinion selected science teachers showed that the module is suitable for teaching Form Two students basic science. Yalmiz (2011) argued that learning could only be promoted through the appropriate method of instruction based on strong theory like Piaget cognitive theory. The authors further assert that instructions that do not bridge the gap between prior knowledge of students and the new learning content do not improve the child's cognitive (mental) and psychomotor (skills) skills. In this study the teacher engages students in a challenging task in the 7E-IIM Constructivist classroom. This task is according to their mental ability and provides opportunities for discussion. Students will get the opportunity to share their views with others, enhance their observation and communication skills, and expand their knowledge through interaction. This module was designed with hands-on and mind-on activities conducted by individual students and in the group. At the same time, the teacher acted as a facilitator with constant feedback in making sure students reach the zone of proximal development (ZPD). This module is structured with a task sheet that engages students in problem-solving activities. The 7E-IIM required students to carry out activities individually and in groups. The module is very engaging, well detailed and self-explanatory.

According to Piaget (1968), the ability of a person to explore information and experience occurs in his or her schemata (Chongo et al., 2021). Children response or manipulative skills reflect the internal structure, which Piaget refers to as schema. The 7E-IIM is designed to reflect the schemata of Form Two students. The researchers are conscious of Piaget's belief that children's schemata change based on mental development (Wadsworth, 1979). The 7E-IIM is developed to ensure individuals assimilate or accommodate information at eliciting or engage stage of the module. In the second stage of 7E-IIM, students are presented with a task sheet to identify and solve a given problem. The module is also designed to help students develop a deep, meaningful understanding of states of matter transformation related to science process skills involved in hands-on activities. 7E-IIM is designed to emphasizes transfer of learning and importance of prior knowledge.

The 7E-Inquiry integrated module is a paradigm of learning that can foster learning. Constructivist, meaningful, and inquiry-based learning concepts underpin this module. The module's specifics were established outside and inside the classroom in order to provide aspiring teachers with a guide and syntax to follow. The seven syntaxes of the 7E-IIM learning model are eliciting, engage, explore, explain elaborate, evaluate, and extend (Eisenkraft, 2003). As illustrated in Figure 1, the implementation of the seven syntaxes is done in cycles and in a sequential order.

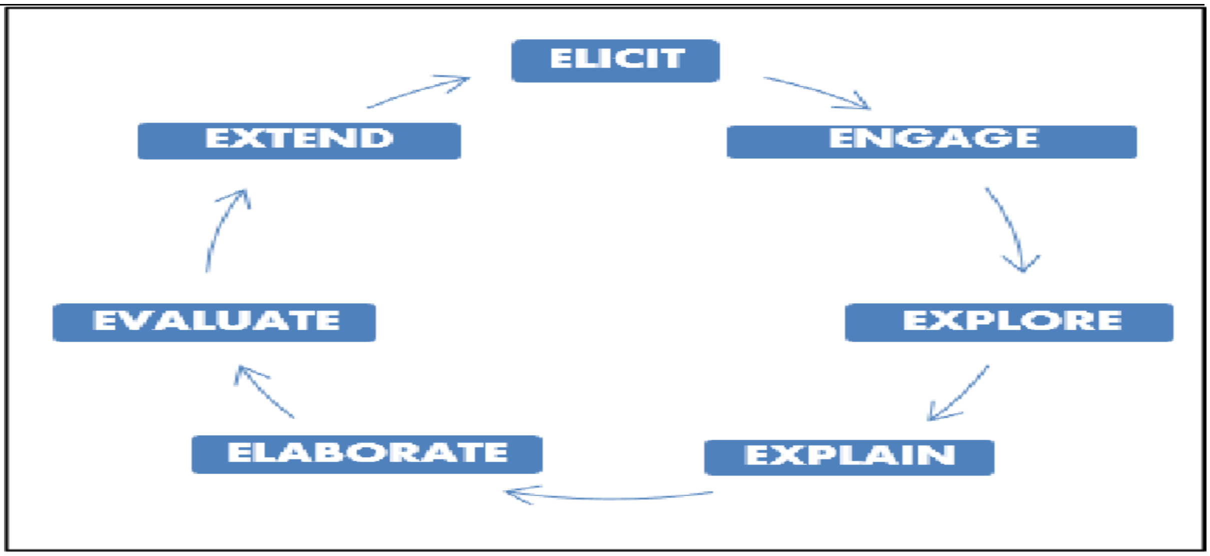

Figure 1. Diagrammatical representation of 7E-learning cycle (George, 2016)

4.0 METHODOLOGY

This study is a pre-post-test design which constitute 39 Form Two students (concrete,22 and formal 17) mean age 13.5 years in one intact class in Junior secondary school setting. The previous knowledge of the subject was similar. Seven weeks was observed for the treatment, 90 minutes per week (45 for theory and 45 for practical class).

4.1 Instruments

Two instruments were used for the collection of data in this study (State of Matter Achievement Test and Lawson Classroom Test of Scientific Reasoning)

The SMAT is a researcher-made achievement test covering the topics included in form two basic science curriculums in collaboration with some science teachers and validated by the selected expert of science teaching. The instrument comprises twenty-five item-test for every aspect of the states of matter concepts (liquid, solid and gases). The test is a multi-choice instrument with three distracters and one correct option. Furthermore, the KR-20 value in the present study was found to be 0.80, which is an acceptable scale. Revised Bloom's taxonomy was used in State of matter table of specification, which shows the relationship between objectives and segment of the content. In the extreme content area process objective and basic concepts of the State of matter unit, 32% constitute the gas state's components, 32% solid-state and 36% liquid state, totalling 100%. From the table of specification, the State of Matter Achievement Test, the components of Solid-state, Liquid state and Gas state have 8, 9 and 8 questions each, respectively. However, validation of the instrument was done accordingly, as explained in this chapter. The instrument was submitted to experts and a few science teachers for face and content validation. After which, the researcher modified the instruments along the lines of comments suggested by the experts. The investigator's table of the specification was developed to ensure participants' assessments are well aligned to the treatment received and the cognitive processes used during instruction. In other word is to ensure that, the content, treatment and evaluation all aligned.

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Table 1
Table of Specification for States of Matter Achievement Test (SMAT)

Topic	**Time spent**	**Domain**		**Objective**	**Total Number of Test items**	
		LLT	HLT		Actual	Adjusted
Solid	160 minutes	5	4	To measure understanding /recalling/analyzing	10	08
Liquid	240 minutes	5	2	To measure understanding/ memorization/identification/ evaluating	10	09
Gas	160 minutes	6	3	To measure understanding applying/evaluating/ synthesizing/recalling	10	08
Total	560 minutes	16	09		30	25

Note: LLT: *Lower level of thinking* ***HLT:*** *Higher level of thinking*

This study's adapted test version has included ten items, administered to assess the concrete and formal stages, and have a reliability 0.85. Students were grouped into concrete and formal cognitive developmental level according to their LCTSR pre-test scores. Other studies have used several versions of the test depending on these versions' suitability to their research aim. Consequently, the number of questions and student cognitive level categorisation differed slightly in these studies. For example, Lawson et al. (2007) used a version of the test with 11 two-tier questions for a total of 22 questions. The authors grouped the students into the concrete developmental cognitive level if they scored between 0 and 9, formal reasoners if they scored between 10 and 18, and post formal developmental cognitive level if they scored between 19 and 22. In another study by Acar and Patton (2016), the authors used a version of the test with 12 two-tier questions and categorised students based on their correct responses to the two-tier question set. Students who scored between 0-5 were categorised as concrete reasoners; those who scored between 6-8 were grouped as formal reasoners, and those who scored between 9-12 were grouped as post-formal reasoners. Based upon the cut-off points used by (Acar & Patton, 2016); (Han, 2013); Lawson (2007), the present Form two basic science students scored between 0-5 and categorised as concrete developmental cognitive level, and those who scored between 6-10 were grouped as formal developmental cognitive level. Therefore, 22 students are classified as concrete developmental cognitive level and 17 as a formal developmental cognitive level.

4.2 Treatment (7E-Inquiry Integrated Module)

Seven weeks was observed for the full implementation of the experiment during the first term of the 2019/2020 academic session. The state of matter unit was taught to Form Two basic science students as part of the standard curriculum. The study was attended by 39 students From One intact classroom. Two periods' times a week was allocated to Form Two basic science classes with 45 minutes per lesson. Students experience 7E-Inquiry Integrated Module (7E-IIM) through hands-on activities, which invariably increases their curiosity and provide them with first-hand information on a given phenomenon. The research assistant uses the researcher developed module throughout the seven weeks. Each module is completed in a week with practical activities. As already mentioned, the

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schools allocated two periods each per week. One week is used for theoretical class, while the other period is utilised for practical hands-on activities.

To ensure compliance with the full implementation of the experiment or when the research assistant needed the attention of the researcher on a given activity, the researcher got involved in the instruction of the subject. During the intervention, participants are introduced to hands and mind-on activities. These involve practical activities that require students to observe, classify, measure, record, and make predictions based on his or her findings. These activities improve their process skills and deepen their understanding. But from time to time on weekly, the researchers hold meetings with the research assistant to ensure full implementation of 7E-IIM. These meetings were often aimed at maintaining contact during treatment and reduce conflicts resulting from learning activities.

5.0 RESULTS

The result of descriptive statistics has shown that the formal reasoners outperformed the concrete reasoners on the multiple-choice states of matter test. Table 1 shows that the mean scored (51.45) by formal cognitive level is greater than the mean achievement score (54.59) of concrete cognitive level. To determine whether the mean difference between the two groups (formal and concrete) is statistically significant, analysis of covariance (ANCOVA) was conducted to assess the effect of student's level of mental operation on their states of matter achievement. The cognitive levels (concrete and formal) serve as independent variable measured by Lawson Classroom Test of Scientific Reasoning (LCTSR). The dependent variable is post-test multi-choice test scores on the unit of states of matter. The covariate is another independent variable that might have influence the results of the dependent variable. To take care of the effect of covariate, the pre-test is treated as covariate. The study control whatever contribution made by pre-test to see clearly if the LCTSR predict the states of matter achievement. The pre-test scores were used as a covariate to remove any variation in the post-test.

Table 2. *Descriptive Statistics*

Cognitive levels	Mean	Std. Deviation	Skewness	Kurtosis	N
Concrete	51.45	4.94	0.86	0.38	22
Formal	54.59	5.77	0.60	-1.01	17

Assumptions such as linearity, linear regression, homogeneity of variance, and normality were checked before conducting ANCOVA (see Table 3). A relationship between covariate (pre-test) and independent variable (LCTSR) was not statistically significant indicating that homogeneity of regression slopes was not violated with a non-significant p-value, $F(2, 36)=2.21$, $p=0.12$, indicating no violation of linearity. Furthermore, the values of skewness and kurtosis ranging from 0.87, 0.60, 0.38 to -1.01 respectively indicated that there was no serious violation of normality assumption.

Table 3. *Summary of Test of Between Subjects Effects*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
LCRSR * pretest01	124.942	2	62.471	2.212	.124	.109
Error	1016.801	36	28.244			

a. R Squared = .109 (Adjusted R Squared = .060)

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ANCOVA was conducted after checking the assumption (see Table 4). The result showed that while there is a mean different between concrete and formal students (concrete=51.45 and formal 54.59), however, there was no statistically significant effect of cognitive level on student states of matter achievement $F(1, 36)= 3.156$, $P>0.05$, also the covariate (pre-test) was not significantly related to participant's states of matter achievement $F(1, 36)= 0.90$, $p>.05$.

Table 4. *Summary of ANCOVA*

Source	df	f	p
Pre-test	1	0.90	.35
LCTSR	1	3.16	.08
Error	36		

A linear regression analysis was conducted to confirm the variable that best describe the student's achievement. The cognitive level of students is the predictor variable while the states of matter achievement measured by multiple-choice test is the dependent variable. As part of assumption associated with regression a scatter plot was conducted and the plots showed negative relationship between the variables (see figure 1). Table 4 showed the value of R to be 0.29. this value represents the correlation between states of matter achievement and Lawson Classroom Test of Scientific Reasoning (LCTSR). The value of R^2 is 0.08 which indicated that LCTSR only accounted for 8% of the variation in states of matter achievement. This shows that 92% of the variation in students' achievement cannot be explained by LCTSR. This tells that other variable such as teaching approach have an influence on students states of matter achievement. Investigating the ANOVA table, the f-ratio which is 3.32 is not significant at $p>0.05$. this result showed that the overall regression model does not predict student's achievement significantly. The result indicated that cognitive levels as measured by LCTSR was not the main predictor of student's achievement.

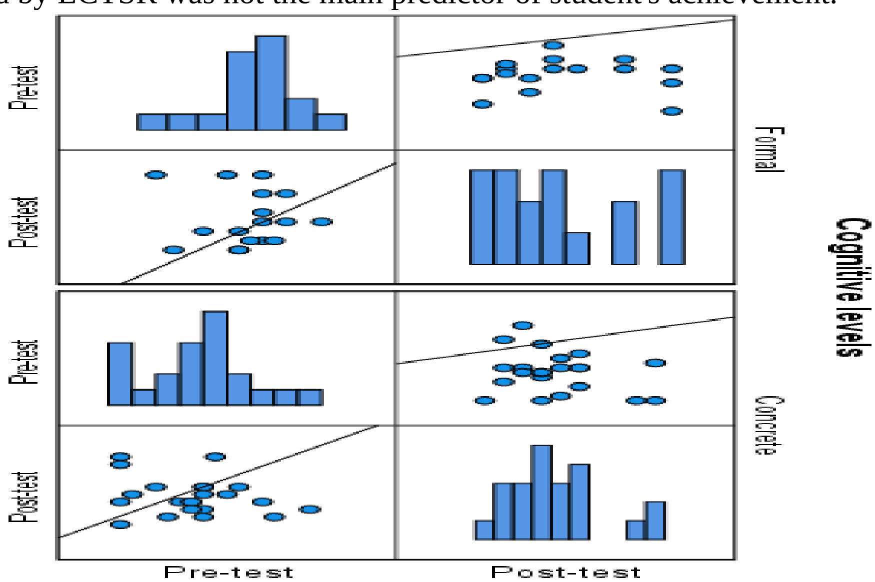

Figure 2. Scatter plot

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6.0 DISCUSSION

The main aim of this study is to determine whether the cognitive level is a strong predictor of student achievement. Finding from the study indicated that there is a higher number of participants at concrete level accounting for 56.6% while formal level account for 43.6% of the total sample, this finding is the same with the finding of Cepni, Ozsevgec, and Cerrah (2004) and Yenilmez et al. (2006) who report that most of their participants are in concrete level. Previous studies have reported that due to the abstract nature of science concept, individuals who have not to reach form reasoning struggled in understanding concept, which resulted in a mismatch to their existing schema (Powell & Kalina, 2009; Yenilmez et al., 2006). Asking inquiry questions to students in class in an attempt to understand their difficulties and challenges in learning concepts help identify the type of students a teacher is teaching in class, and this allows the teacher render necessary assistance to ensure students have learned. The findings from this study are in disagreement with some previous studies who report the positive influence of student's cognitive level on achievement. Cepni et al. (2004) argued that an instructional approach systematically designed based on strong instructional theories can enhance individuals learning regardless of their level of reasoning ability or cognitive levels. This is the case with the present study. Individuals are assigned various activities to explore knowledge with the constant support of the teacher. All these and many are the reasons the present findings are contrary to the previous studies on the influence of student's cognitive levels or reasoning ability on their achievement (Huppert, Lomask, & Lazarowitz, 2002; Karbach et al., 2013; Mari & Gumel, 2015; Vilia, Candeias, Neto, Franco, & Melo, 2017; Yenilmez et al., 2006). In other words, the findings of these study showed that the cognitive stage is not a strong predictor of achievement. Therefore, it may not be out of context to conclude that student's achievement in this study is accounted by the potential influence of instructional strategy adopted in teaching the subject (7E-Inquiry Integrated Module).

The present finding showed that teaching within the individual structure led to meaningful learning and closed the gap that exists in individuals learning ability. Presumably, the previous studies failed to consider individual differences in comprehension, which require a systematic instructional approach that provides equity and equality in learning science. Piaget believed that instructions not within the individual schema is bound to fail (Piaget, 1976). Choosing a suitable and sophisticated approach is crucial for meaningful to occur. Researchers and educators have agreed that individuals do not learn in the same way (Lahti, 2013). This implies that there are low and high reasoners in every classroom and hence the need for teachers to identify the nature and mental structure of his or her students and choose appropriate instruction that takes into cognisance the individual learning difference. It was reported that the constructivist learning approach enhances low intelligent student's performance to acquire knowledge and comprehends information (Adak, 2017). In summary, this study has confirmed the effectiveness of preparing instruction according to student's reasoning level. This study has shown that instructional; approach that is hands-on ensure leading and deepens the understanding of students.

7.0 IMPLICATION FOR TEACHERS

This study has proven that individuals can learn and achieve better scores if provided opportunities to explore information themselves. The results indicated that providing equity in the classroom ensures equality of outcome across students of different cognitive developmental levels. Observations from this study suggested that a certain approach is preferable for the level of cognitive development of students, if not quite necessary, for them to understand the transformation and properties of matter and its states as acknowledged by Özmen (2011) and Tsitsipis, Stamovlasis, and Papageorgiou (2010). Therefore, instructors should adopt instructional strategies that recognise the individual difference and provide an opportunity for all individuals to learn regardless of their mental ability.

8.0 ACKNOWLEDGEMENT

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