International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

http://ijpsat.ijsht-journals.org
Vol. 30 No. 1 December 2021, pp.146-155

Improving High School Student's Procedural Understanding of Electricity and Magnetism Using Scaffold Analogical Reasoning Instruction

Aysheshim Mengistu[1], Shimels Assefa[2], Desta Gebeyehu[3]

[1,2,3]Addis Ababa University
Science and Mathematics Education
Addis Ababa University, AAU
Addis Ababa, Ethiopia

Abstract— Simulated analogical teaching method has a unique contribution in enhancing students' learning. This study aims to analyze effect of simulated analogies scaffold by group discussion method in improving students' procedural understanding of some selected formulas and problems of electricity and magnetism at high school level. The study involved 75 grade 10th students from two different high schools, namely Dagmawi Twodros and Fert high schools found in Debre Tabor Town, South Gondar, Amhara region, Ethiopia. A quasi-experimental method with pretest posttest design was used in the study. An adapted standardized test of electricity and magnetism procedural understanding test (EMPUT) was used to collect data. The reliability of EMPUT was checked and found to be at about .86. After checking all the necessary assumptions, an independent sample t-test was used to analyze the mean difference on students EMPUT scores between groups and further the mean difference was achieved due to the effect of treatment answered by comparing the number of achiever level of students between the experimental and control groups. From the result analysis, we found that experimental group who used simulated analogies scaffold by group discussion method in learning of electricity and magnetism showed a higher mean score of EMPUT than the control group. The number of medium, high and very high achiever students were larger for experimental group than the control group. Thus, it can be concluded that the use of simulated analogies scaffold by group discussion model improved high school students' procedural understanding of electricity and magnetism. So, from the finding of this study, it is recommended that other science field teachers can use simulated analogies scaffold by group discussion method to improve students' understanding to the desired level.

Keywords— Electricity;Magnetism; Group Discussion; Procedural Understanding; Simulated Analogical Instruction.

I. INTRODUCTION

Education has played a great role in improving human life to the optimal level. The quality of education predicts the development of a nation in its all-rounded aspects such as the presence of multi-dimensional industries, manufacturing, health organizations, and agricultural institutions, with high quality and quantity productions, and others. Therefore, the education sector in a nation led the quality and productiveness of other sectors. Physics has also contributed to the prosperity of nations. Physics, as it is one of the

Corresponding Author: Aysheshim Mengistu

pillars in the education system, played in creating awareness and equipping human beings with necessary knowledge, skills, and attitudes to investigate the different aspects of nature, increasing creativity to solve problems that occurred in daily life situations.

Governments across nations put an intensive effort to improve their education system in general, physics education in particular to their education curriculum being implemented in line with the real context of the technologically advanced world. Even though efforts were made in improving quality of education, there were a big obstacle observed in the system regarding the decline of students' achievement and performance in science fields specifically in physics ([1], [2], [3], [4], [5]). The reports all showed that students' understanding of physics at every education pyramid needs special attention.

Several studies across the world indicated that students' physics achievement deteriorated [6] and they did not enjoy learning physics ([7], [8]). In the Ethiopian context, grade 10th students' Physics achievement mean score in the national examination was very low as compared to the crude pass mark (50%). The report indicated by the Ministry of Education ([9], [10], [11]) showed that high school typically grade 10th students physics achievement was the least and even very shocking (31.2% in 2010, 35.45 in 2014 and 29.43% in 2017).

Many studies were conducted to investigate factors that hinder students' physics understanding. Teacher way of teaching physics are inappropriate ([12], [13], [3], [14], [15]). These studies indicated that the instructional method used by physics teachers did not enhance students' Procedural knowledge as it was monotonous from the beginning to the end of the lesson.

Procedural understanding by students in their physics learning can be explained through test achievement where the test items need their abilities to synchronize and use multiple physics formulas and reaching to the final correct answers. The level of procedural understanding is also expressed by using an appropriate physics formula to solve physics problems as it is presented in a different form ([15], [16]).

Understanding physics formulas are very important for learners to solve physics problems through an approach of mathematical equations Some studies indicated that students in a rare case memorize physics formulas but after some time they failed to apply in solving problems which were presented in a different approach as examples used in classroom teaching([17]. [18] also claimed that high school students were unable to combine multiple physics formulas to solve physics problems that demand procedural understanding.[15] indicated that the main problem observed in the physics classroom teaching is that physics teachers did not use a teaching method that allow students to understand the presented content and objectives as desired. A study conducted by [19] concluded that student's physics teaching and learning at any school level be effective and meaningful if the teaching process is scaffold by existing facilities, learner's prior knowledge, and experience.

The above-aforementioned studies indicated that instructional strategies such as the lecturing method makes procedural understanding difficult for students because of the monotonicity of the teaching method. The studies all were recommended that investigating an effective and alternative physics classroom instruction is one of the research areas to be further studied. Therefore, this situation can be overcome if appropriate active learning methods that can enhance students physics learning typically procedural understanding to the optimal level.

Even though there are many factors that affect students' physics procedural understanding, it is important to have an appropriate teaching method that links student's prior knowledge, prior experience and is implemented by physics teachers at high school level in order to enhance students' procedural understanding in physics in general, electricity and magnetism in particular.

Analogy-based instruction is one of the suggested active learning methods that focused both on declarative and procedural knowledge ([20], [21], [22], [23], [24]). Procedural understanding in physics learning is about the development of cognitions that needs students' abilities to link prior knowledge, understanding, and experience with the new information to be learned [25] Therefore, from the use of learners' prior experience and understanding, analogy-based instruction is an alternative method of teaching to facilitate physics learning.

From the point of view in using learners' prior knowledge including students' prior experience and understanding for the learning of new contents in physics, this study was implemented an alternative physics classroom teaching method called simulated analogies scaffold by a group discussion to improve high school students procedural understanding of some selected contents (

electric force, electric field strength, electric potential, and potential energy, equivalent resistance of resistors connected in series and parallel, resistance of wire, and magnetic field strength) at grade 10th level.

Analogy-based instruction is very helpful to make a synergy of familiar things, understanding, and thoughts with the new one to be learned in a lesson. The effect of this instructional strategy was studied and reported by many researchers ([26], [27], [28], [29]). But still, students' physics achievement and their procedural understanding were not changed as expected. These studies were come up with positive and negative effects of analogy-based instruction on students' physics learning. The studies showed that students have difficulties with procedural understanding due to the fact that students usually failed to identify the point where the analogy breaks, and they were unable to see the analogy itself, simply remembered the analogy instead of the equation or physics formula being learned. In this study, we used simulated analogies by scaffolding with group discussion method in the physics classroom to treat the selected contents of electricity and magnetism at the high school level. The theory of social constructivism guided the use of simulated analogies scaffold by group discussion method for treatment group in the learning of electricity and magnetism.

Simulated analogies were first displayed by the physics teacher by the use of projectors and plasma television for students. Students were taking individual notes and retrieving what they knew about the presented analogy individually, and soon the display had finished, students discusses in a group of four to map similar attributes between the source domain(analogue) to the target domain(new content to be learned) through the guidance of structural mapping theory. The teacher had a facilitation role during group discussion by raising leading questions. Once similar attribute between the two domains were made, both students and the teacher were identified the unmapped attributes presented in the analogy so as to indicate the breaking point of the simulated analogy. Once, the mapped and unmapped attributes of the simulated analogies presented by the teacher were identified, students were engaged and interact each other within the group and across the group so as to transfer the prior information, experience and knowledge for the learning of new information and making meaningful knowledge. To this end, the simulated analogy scaffold by group discussion method can fit with Ethiopian physics education system at high school levels.

Therefore, this study went to scaffold analogical reasoning instruction by a means of simulation and group discussion to tackle students' physics learning problem. This study was aimed to investigate the effect of simulated analogical reasoning scaffold by group discussion on high school students' Procedural understanding of electricity and magnetism at grade 10th level in Ethiopian context. To achieve this research objective, it was hypothesized that there was no statistically mean score difference on students' Procedural understanding test between groups who were treated with simulated analogical reasoning scaffold by group discussion over comparison groups who were learned the same contents of electricity and magnetism using conventional method.

II. MATERILS AND METHODS

For this study, a non-equivalent quasi-experimental method with pretest-posttest design was used to investigate the effect of simulated analogies scaffold by group discussion on high school students' procedural understanding of electricity and magnetism. Grade 10th students who were found in Debte Tabor Town, South Gondar, Amhara Region, Ethiopia were used as a sample to conduct the desired teaching model. Participant students from two high schools namely, Dagmawi Tewodros and Fert secondary schools were selected randomly. One section grade 10th students from each high school were selected randomly for experimental and control group. The participant grade 10th students from Tewodros secondary school were experimental groups who were used simulated analogies scaffold by group discussion method whereas students form Fert secondary school were selected as control group who learned treated the same contents of electricity and magnetism using conventional methods. Grade 10th students were selected as a sample for this study due to their age level, 14 to 16 years old, be able to link prior understanding with the new information presented through the use of analogies and in addition the contents of electricity and magnetism which are suitable to use analogy based instruction are found with an in depth manner at this grade level. An instructional material was developed by the researcher for teaching of selected contents of electricity and magnetism (electric force, electric field, capacitance, electric potential, and electric potential energy, electric current, voltage, battery, resistance in series and parallel, resistance of a wire, magnetic field and magnetic force) through the use of simulated analogies and presented in support of group discussion for experimental groups.

TABLE I. Groups Intervention Procedures.

Group	*Pre-Test*	*Treatment*	*Post-Test*
Experimental Group (EG)	O_1	X	O_2
Control Group (CG)	O_1	-	O_2

O_1: Pre-test used to see students' Procedural Understanding level before intervention.

X: Simulated Analogies Scaffold by Group Discussion Method Used by EG only.

O_2: Post-test used to see students' Procedural Understanding level after intervention.

Electricity and Magnetism Procedural Understanding test (EMPUT) of 14 multiple choice items including remembering, understanding and apply physics formulas to solve problems by adapted it from different standardized tests was used to collect data. Pre-test was administered before the start of intervention for both experimental and control groups. After giving a training on the designed instructional material about the implementation of simulated analogies and mode of delivering the contents through group discussion for experimental group physics teacher, the intervention was made for a couple of 8 weeks. The simulated analogies were presented by the physics teacher through the use of plasma television found in the physics classroom. The researcher had made a support for the physics teacher both in planning and discuss the ways of implementing the designed simulated analogies in the physics lesson. Then after the end of intervention, a post test of electricity and magnetism procedural understanding test (Post-EMPUT) was administered for both experimental and control groups.

Once both the pre-test and post-test data of procedural understanding of electricity and magnetism were collected, coded and entered into SPSS version 26, assumptions of test statistics were checked to evaluate a statistically significant mean difference in the pre-test and post-test scores between the two groups was exist or not. By checking the assumptions of normality and homogeneity of data, we found that none of them was not markedly violated, so that an independent sample t-test was used to test the mean difference between the two groups statistically significant or not.

III. Result and Discussion

The sampled grade 10th students' Pre-EMPUT and Post-EMPUT mean scores were collected before and after intervention. The mean scores were indicated in the figure 1 below.

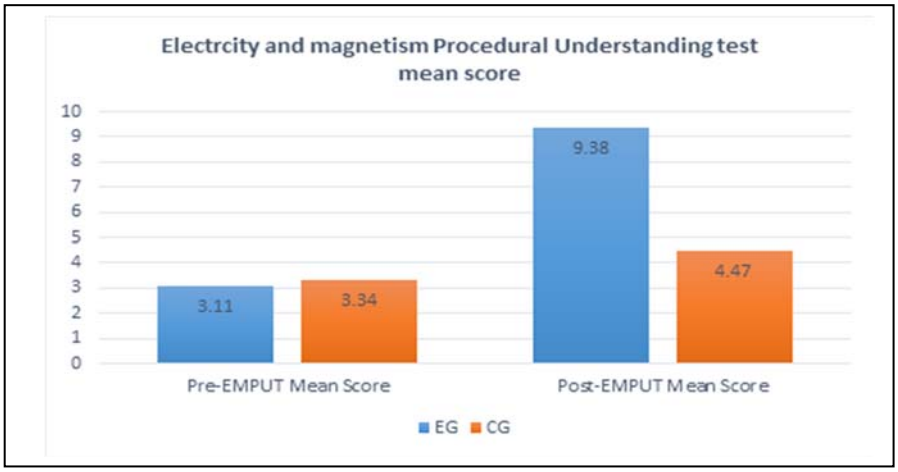

Fig. 1. Students' Procedural Understanding Pre and Post test Scores of Groups.

The above figure 1 indicated that there was a mean difference on Pre-test score of EMPUT between the experimental and control groups. Thus, to check whether this mean difference was statistically significant or not the assumptions of normality and test of

homogeneity of variance were checked and evaluated. Here, an independent sample t-test was run to evaluate whether the pre-test mean score of electricity and magnetism was statistically significant or not. The result analysis was presented below.

TABLE II. Descriptive Statistics Of Pre- And Post-Emput Scores By Groups.

	Pre-EMPUT Score					**Post-EMPUT Score**			
	N	***M***	***SD***	***Skew***	***Kurtosis***	***M***	***SD***	***Skew***	***Kurtosis***
EG	37	3.11	1.13	-.100	-.62	9.38	2.26	-.363	.678
CG	38	3.34	1.40	.031	-.80	4.47	2.46	.397	-.514

As can be seen on Table II above, the skewness and kurtosis of Pre-EMPUT scores for each group showed that the values were found in the rage between ±1 indicated that the test data were approximately normally distributed and hence this assumption was not markedly violated. The test of normality by Shapiro-Wilks test of Pre-EMPUT score for each group were not significant, W(37)=. 92, p= .054 for EG and W(38)=.94, p=.057 for CG respectively which indicated that test data were approximately normally distributed.

In addition, the assumption of homogeneity of variance was tested and satisfied using Levene's F test, F (73) =2.83, p=.097 shown on table III below. It was hypothesized that there was no a statistically significant mean difference on Pre-EMPUT score between the experimental group (M=3.112.97, SD=1.13) and control group (M =3.34, SD=1.40). To test this null hypothesis, an independent sample t-test was used and the results were reported below.

TABLE III. Levene's test and Independent sample t-test results of Pre-EMPUT scores between Groups.

Independent sample Test										
	Levene's Test			***Test of Equality of Means***					***CI 95%***	
Pre - EMPUT	Equal variance assumed	F	sig	t	df	sig	MD	SE	Lower	Upper
		2.83	.097	.796	73	.428	.234	.293	-.351	.819

The independent sample t-test on Table III showed above that there was no a statistically significant mean difference on Pre-EMPUT score between experimental and control groups, t (73) =.796, p =.428. This indicated that we were not able to reject the null hypothesis. The result analysis revealed that both the experimental and control group high school students were found on the same level of electricity and magnetism procedural understanding.

After an intervention had made for the experimental group using simulated analogical reasoning scaffold by group discussion in learning procedures of electricity and magnetism and control group was learned by any conventional method, a Post-EMPUT was administered. The assumption of normality was not violated as skewness and Kurtosis is found in the range of ± 1 as shown on table 1 above. Therefore, Post-EMPUT score data was approximately normally distributed. The assumption of homogeneity of variance was tested and satisfied via Levene's F-test, F=1.17, p=.283 as indicated in Table IV below. To examine the difference on Post-EMPUT between groups significant or not, it was hypothesized that there was no statistically significant difference on the mean Post-EMPUT score between experimental and control group. To test this null hypothesis, an independent sample t-test was used and the results were presented below.

TABLE IV. Levene's Test And Independent Sample T-Test Result Of Post-Emput Scores Between Groups.

Independent sample Test										
	Levene's Test			***Test of Equality of Means***					***CI 95%***	
Post - EMPUT	Equal variance assumed	F	sig	t	df	sig	MD	SE	Lower	Upper
		1.17	.283	-8.98	73	.000	-4.90	.546	-5.99	-3.81

The independent sample t-test was performed to compare the mean score difference on Post-EMPUT between experimental and control groups. As predicted on Table IV, the experimental groups scored a statistically significant larger mean (M=9.38, SD=2.26, N=37) than the control group (M =4.47, SD=2.46, N=38), t(73)=-8.98, p<.001, two tailed. So that we reject the designed null hypothesis. That is the experimental group showed a statistically significantly larger mean in Post-EMPUT than the control group. Cohen's d was estimated at 2.08, which is much larger effect based on [30] guideline. The mean difference of the test score with the 95% confidence interval around the difference between group means was relatively precise (-5.99 to -3.81). Therefore, the result analysis asserted that the change in mean score for procedural understanding of electricity and magnetism achieved because of the teaching method used by the experimental groups.

The mean scores of Pre-EMPUT scores for CG and EG were 3.34 and 3.11, and their Post-EMPUT mean scores were 4.47 and 9.38 as shown in the figure 1 above. The two groups showed a better mean score change after treatment. But to identify which learning method help groups to achieve a larger mean, normalized learning gain $\langle g \rangle$ was calculated using the formula:

$$\langle g \rangle = \frac{(\%Post - \%Pre)}{(100 - \%Pre)}$$

The normalized learning gain was found to be .11 for CG who were learning selected topics of electricity and magnetism with a conventional method and .58 for EG who were treated with simulated analogical reasoning scaffold by group discussion method in their learning of the selected contents of electricity and magnetism respectively. The normalized learning gain for CG .11 was low and for EG .58 was medium [31]. From the mean normalized learning gain result analysis, it is possible to say that using simulated analogical reasoning scaffold by group discussion help to enhance students' procedural understanding of electricity and magnetism than conventional method of teaching.

From the Pre-EMPUT and Post-EMPUT score which was changed in to percentage and counted the number of students who achieved low(average score< 41%), medium(41%≤Average score<61%), high(61%≤ average score<81% and very high(Average Score≥ 81%)[15]. The number of students in the experimental and control group achiever level was reported in the following Table V below.

TABLE V. Students" Achiever Level In Pre- And Post- Emput Score Results.

Experimental Group(EG)						**Control Group(CG)**				
	Low	***Medium***	***High***	***Very High***	***Total***	***Low***	***Medium***	***High***	***Very High***	***Total***
Counted Pre-EMPUT	36 (97.3%)	-	1 (2.7%)	-	37 (100%)	36 (94.7%)	2 (5.3%)	-	-	38 (100%)
Counted Post-EMPUT	1 (2.7%)	9 (21.6%)	20 (56.8%)	7 (18.9%)	37 (100%)	25 (65.8%)	12 (26.3%)	1 (7.9%)	-	38 (100%)

Experimental group students' achiever level in their Pre-EMPUT score as indicated in table 5, were 97.3% of the total students in this group found as low achievers and only one students (2.7%) found to be in the category of high achiever. Similarly, 94.7% of students from the control group were found to be in the low achiever level and two students (5.3%) were medium achievers. But after treatment, the Post-EMPUT score analysis showed that 0nly 2.7% of students from the experimental group found to be low achiever, where as 21.6% were medium achievers, 56.8% became high achievers and 18.9% were found to be very high achievers. The Post-EMPUT score analysis also indicated that 65.8% of students from the control group were still found under low achiever category, where as 26.3% and 7.9% of students were found to be medium and high achievers respectively.

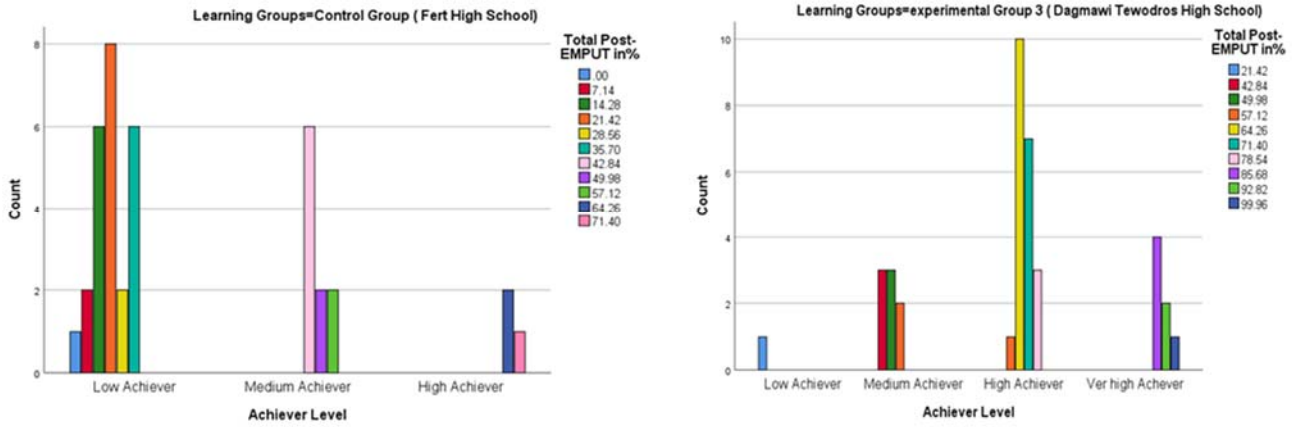

Fig 2. Achiever Level of Groups in their Post-EMPUT Scores.

As can be seen from figure 2 above, the number of low achievers in the control group were reduced from 36 to 25 (94.7% to 65.8%). After the learning of contents of electricity and magnetism using conventional method for this group, some of the low achiever students (10) were moved up to medium and high achiever levels. That is the number of medium achievers were increased from 2 to 12 (5.3% to 26.3%). Only one count (student) was found to be a high achiever. From the experimental group, only one students was left as a low achiever (2.7%) where as the number of medium achiever students increased from zero to 9 after intervention (21.6%) and the number of high achievers were increased from 2.7% to 56.8% and the number of very high achiever students was found to be 18.9%. Therefore, the effect of using simulated analogies scaffold by group discussion visibly enhanced the number of medium achievers dominantly, high and very high achievers with a better number than the control group who was learned the same contents of electricity and magnetism which demands procedural understanding.

The purpose of this study was to determine whether or not simulated analogies scaffold by group discussion method improved high school students procedural understanding in learning of some selected contents of electricity and magnetism at grade 10th level in Ethiopian context. Several studies related to the effect of analogy based instruction on students' physics formula usage and understanding were studied and come up with controversy results. In this study, it was hypothesized that grade 10th high school students who were treated the learning of some selected electricity and magnetism mathematical equations with simulated analogies scaffold by group discussion showed a better understanding than students who learnt the same procedures with conventional method. The result of test analysis showed that simulated analogies scaffold by group discussion method help students to had better procedural understanding of selected mathematical equations of electricity and magnetism than control groups. This result is consistent with other previous research findings in that analogical reasoning method can facilitate students' procedural understanding ([32], [33], [34], [35]).

The finding of this study revealed that students' procedural understanding of some selected physics formulas in relation to electricity and magnetism in high school level enhanced when simulated analogies were used in support of group discussion method. The result of this finding was in accordance with the study carried out on the use of analogies as it helps learners to visualize the similarities of analogy and the new physics formula to be learned [36].

Several studies also showed that when analogies were supported by either other instructional strategy or plat forms creating a good environment for students to visualize the anlogy, students abilities of understanding abstract contents increased([27], [28], [37]) which supported the finding of this study as the mean score of students procedural understanding after treated with simulated

analogies used for linking the analogue with the new target physics formulas to be learned and make that link by forming a structural mapping through group interaction with a significant amount.

The result of this study showed that simulated analogies scaffold by group discussion method enhances students' problem solving using appropriate formulas by creating an opportunities for visualizing the common features between the new physics procedure to be learned and the analogy presented and helping students to see the analogies.

IV. Conclusion

This study showed that simulated analogies had improved high school students' procedural understanding of contents of electricity and magnetism when it is scaffold by group discussion method. The great efforts made in this study can contribute an information to the physics education research community, physics educators and teachers about the use of analogies by scaffolding it with technology and other active learning method to bring a better students' procedural understanding in their learning. This study has indicated that when simulated analogies scaffold by group discussion method used systematically, students' procedural understanding of different contents of electricity and magnetism improved more. From the finding of this study, it is recommended that other science subject teachers can use simulated analogies scaffold by group discussion method in their classroom teaching so as to improve students understanding. For further studies, this studies open a gate for researchers to look at the effectiveness of analogical reasoning method blending with other type of active learning methods for learning of other branch of physics and other science fields such as chemistry and mathematics.

Acknowledgment

This study was successful with the great help of my advisors Dr. Shimels Assefa and Dr. Desta Gebeyehu for their unreserved efforts for commenting and suggesting through proof reading of the paper. I thank both of them for their contributions the many regards.

References

[1] Mullis, I. V., & Martin, M. O. TIMSS 2019 Assessment Frameworks: ERIC,2017.

[2] Musasia, A. M., Ocholla, A. A., & Sakwa, T. W. Physics Practical Work and Its Influence on Students' Academic Achievement. Journal of Education and Practice, 2016, 7(28), 129-134.

[3] Njoroge, G., Changeiywo, J., & Ndirangu, M. . Effects of inquiry-based teaching approach on Secondary School Students' achievement and motivation in Physics in Nyeri County, Kenya. International Journal of Academic Research in Education and Review, 2014, 2(1), 1-16.

[4] OGUNLEYE, B. O., & Ojo, O. R. Impact of physical fitness activities on students' Basic Science achievement in selected Nigerian secondary schools, 2019.

[5] Stephens, M., Landeros, K., Perkins, R., & Tang, J. H. Highlights from TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of US Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context. NCES 2017-002. National Center for Education Statistics,2016.

[6] Murphy, S. The impact of school disadvantage on senior secondary science: A study of patterns of participation and achievement in government secondary schools in Victoria, Australia. Research in Science education, 2020, 50(4), 1603-1618.

[7] Adeyemo, S. A., & Babajide, V. F. Effects of mastery learning approach on students' achievement in physics. International Journal of Scientific & Engineering Research, 2014, 5(2), 910-920.

[8] Bal-Taştan, S., Davoudi, S. M. M., Masalimova, A. R., Bersanov, A. S., Kurbanov, R. A., Boiarchuk, A. V., & Pavlushin, A. A. The impacts of teacher's efficacy and motivation on student's academic achievement in science education among secondary and high school students. Eurasia Journal of Mathematics, Science and Technology Education, 2018, 14(6), 2353-2366.

[9] Molla, T. Educational aid, symbolic power and policy reform: The World Bank in Ethiopia. London Review of Education, 2019, 17(3), 331-346.

[10] MoE, M. o. E. Asessment of Planning and Programming of GEQIP Implimentations by Implimenting Entities., 2017, Unpublished.

[11] NLA, N. L. A. Report on Ethiopian grade10 and 12 National examination Result Assessment, 2013, Unpublished.

[12] McColgan, M. W., Finn, R. A., Broder, D. L., & Hassel, G. E. Assessing students' conceptual knowledge of electricity and magnetism. Physical Review Physics Education Research, 2017, 13(2), 020121.

[13] Mekonnen, S. Problems challenging the academic performance of physics students in higher governmental institutions in the case of Arbaminch, Wolayita Sodo, Hawassa and Dilla Universities. Natural science, 2014.

[14] Noh, N. M., Wong, K.-T., Yeop, M. A., & Abdullah, N. Blended learning: its implementation and promote continuing e-learning environment among student-teachers. International Journal of Advanced and Applied Sciences, 2016, 3(11), 12-15.

[15] Polonia, B. S. E., & Ravi, A. Effect of Direct Instruction Models Toward Students' Understanding of Physics Formula. Berkala Ilmiah Pendidikan Fisika, 2020, 8(2), 133-143.

[16] Sarwar, G. S., & Trumpower, D. L. Effects of conceptual, procedural, and declarative reflection on students' structural knowledge in physics. Educational Technology Research and Development, 2015, 63(2), 185-201.

[17] Serbin, K. S., Robayo, B. J. S., Truman, J. V., Watson, K. L., & Wawro, M. Characterizing quantum physics students' conceptual and procedural knowledge of the characteristic equation. The Journal of Mathematical Behavior, 2020, 58, 100777.

[18] Bautista, R. G. The convergence of Mayer's model and constructivist model towards problem solving in Physics. Convergence, 2012, 3(10).

[19] Putri, E. IMPROVING THE PHYSICS EDUCATION ACHIEVEMENT WITH MAPPING CONCEPT. Asian Journal of Natural & Applied Sciences, 2017, Vol, 6, 4.

[20] Lin, J.-W., & Chiu, M.-H. Evaluating Multiple Analogical Representations from Students' Perceptions Multiple Representations in Physics Education ,2017,pp. 71-91: Springer.

[21] Maharaj-Sharma, R., & Sharma, A. Analogies in Physics Teaching: Experiences of Trinidadian Physics Teachers. Electronic Journal of Science Education, 2017, 21(4).

[22] Okoronka, U. A., & Wada, B. Z. Effects of analogy instructional strategy, cognitive style and gender on senior secondary school students' achievement in some physics concepts in Mubi Metropolis, Nigeria. American Journal of Educational Research, 2014, 2(9), 788-792.

[23] Opfermann, M., Schmeck, A., & Fischer, H. E. Multiple representations in physics and science education–why should we use them? Multiple representations in physics education, 2017, pp. 1-22: Springer.

[24] Rankhumise, M. P., & Imenda, S. N. Using a bicycle analogy to alleviate students' alternative conceptions and conceptual difficulties in electric circuits. Mediterranean Journal of Social Sciences, 2014, 5(15), pp. 297-297.

[25] Rittle-Johnson, B., Fyfe, E. R., & Loehr, A. M. Improving conceptual and procedural knowledge: The impact of instructional content within a mathematics lesson. British Journal of Educational Psychology, 2016, 86(4), 576-591.

[26] Richland, L. E., & Begolli, K. N. Analogy and higher order thinking: Learning mathematics as an example. Policy Insights from the Behavioral and Brain Sciences, 2016, 3(2), 160-168.

[27] Ugur, G., Dilber, R., Senpolat, Y., & Duzgun, B. The effects of analogy on students' understanding of direct current circuits and attitudes towards physics lessons. European Journal of Educational Research, 2012, 1(3), 211-223.

[28] Wang, L., Zhang, J., Jiang, B., & Zhao, H. Application of Analogy Method in the Electromagnetism Teaching in College Physics. Paper presented at the 2016 6th International Conference on Mechatronics, Computer and Education Informationization (MCEI 2016).

[29] You, K. Y. Analogy and Historical Approaches to Undergraduate Electromagnetic Education. Journal of Engineering Education Transformations, 2019, 32(3), 40-47.

[30] Cohen, J. A power primer. Psychological Bulletin, 1992, 112(1), 155.

[31] Hake, R. R. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 1998, 66(1), 64-74.

[32] Akçay, N. O., & Doymuş, K. The effect of different methods of cooperative learning model on academic achievement in physics. Journal of Turkish Science Education, 2014, 11(4), 17-30.

[33] Bigozzi, L., Tarchi, C., Fiorentini, C., Falsini, P., & Stefanelli, F. The influence of teaching approach on students' conceptual learning in physics. Frontiers in psychology, 2018, 9, 2474.

[34] Cinyere, N., & Madu, B. Effect of analogy teaching approach on students' conceptual change in physics. Greener Journal of Educational Research, 2014, 4(4), 119-125.

[35] Davies, K. Teaching by analogy: Gravity and electrostatics: The University of Texas at Dallas, 2014.

[36] Djudin, T., & Grapragasem, S. The Use of Pictorial Analogy to Increase Students' Achievement and Its Retention of Physics Lessons of Direct Current. Jurnal Penelitian Fisika dan Aplikasinya (JPFA), 2019, 9(2), 140-151.

[37] Zipke, M., Ingle, J. C., & Moorehead, T. The Effects of Modeling the Use of Technology with Pre-Service Teachers. Computers in the Schools, 2019, 36(3), 205-221.