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Improving secondary school students' physics achievement through scaffold simulated analogical reasoning strategy

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ABSTRACT

This study was aimed to investigate the effect of simulated analogical reasoning blended with group discussion method on secondary school students' physics achievement. A total of 120 grade 10th students from three different high schools found in Debre Tabor Town, Ethiopia was selected and assigned as three experimental groups randomly to be treated through simulated analogical reasoning blended with group discussion method, concrete analogical reasoning method blended with group discussion method and alone in the learning of contents of electricity and magnetism. A quasi-experimental design was used. Electricity and magnetism performance test was employed to collect data. One-way ANOVA result indicated that students who used simulated analogical reasoning blended with group discussion method achieved a significant larger mean score in their performance test than other groups. To this end, this teaching method is more effective to enhance students' achievement than other model of analogy-based instructions.

Keywords: achievement, electricity, magnetism, simulated analogical reasoning

INTRODUCTION

Education is the corner stone of every nation's economy development and social changes. Science education has been playing its own contribution in facilitating the shifts of moving the economy and human living status from the peripheral level to middle and high-level standards. Physics as one of science education discipline has also its own positive impact on the economic and social development especially on the innovations of science and technologies that basically makes life simple. The advancement and emerging of information and technology make things accessible to everyone in the world and it plays its own role in education as well.

Physics is a branch on natural science where it enables human to understand both nature and phenomenon found around using natural laws and principles. The knowledge of physics helps us to bring many innovations that directly or indirectly assisted our own way of life, performing tasks with the aid of technologies, explaining natural phenomenon concepts, and creating mental models for the transfer of information.

Electricity and magnetism are one branch of physics where people today used it at homes, institutions, and others. Different utensils, electronics materials such as refrigerators, televisions, computers, printing machineries, heaters and others needed electricity and magnetism. So, this disciple of physics is highly related with individual life situations. Due to its large advantage, governments in the world invested in improving and creating conducive environments for science education in general, physics education in particular (Bruns et al., 2011; Kapur et al., 2011). In Ethiopia, the federal government has been investing different dams including the great renaissance dam, for generating electricity with a vast amount (Getie & Jember, 2022; Goshu & Woldeamanuel, 2019). The education system in this regard expected to prepare youths with relevant knowledge and skills to sustain the needs of the country in this regard.

Even if multiple programs and efforts made in education in general, science education across the globe, students have multi problems and learning difficulties in physics, and their achievement was low in this particular branch of natural science (Alonzo & Gotwals, 2012; Bryan et al., 2011; Kaptan & Timurlenk, 2012; Mullis & Martin, 2017; NRC, 2013; OECD, 2014). In Ethiopian situation, secondary school education has a problem of quality (Awayehu, 2017; ESDP, 2002; Eshetu, 2014; Goshu & Woldeamanuel, 2019; Joshi & Verspoor, 2012). Ethiopian secondary school students' achievement in physics was very low and not encouraging (Agbele et al., 2020; Goshu & Woldeamanuel, 2019; Hamelo, 2016; MoE, 2017). Besides, multiple studies and reports indicated that students' learning difficulties in terms of content domains of physics were identified. The studies showed that students have learning difficulties in electricity and magnetism domain of physics (Bao & Koenig, 2019; Dega et al., 2013; Ding et al., 2006; Glauert, 2009; Hamid et al., 2017; Jibril, 2021; Li & Singh, 2016; MoE, 2017).

The first and second national learning assessment reports indicated that Ethiopian grade 10th students' achievement in physics was very low as compared to other subjects like biology, chemistry, English and mathematics (MoE, 2017; NLA, 2013) and even it was very far below the minimum learning competency (50%) set by the ministry of education (TGE, 1994). The mean scores of 10th grade students in physics were 35.94% in the first national learning assessment report and 29.43% in the second national learning assessment. Here, the trained of 10th grade students' achievement in physics was decreasing. In addition, the second national learning assessment report analysis based on physics content domain was analyzed. The report showed that 10th grade students' score at about 31.16% in electricity and magnetism, which indicated that students have learning difficulties in this area of physics.

A number of studies were carried out in identifying factors that hinder students learning of physics at every school level (Agbele et al., 2020; Bao & Koenig, 2019; Beyessa, 2014; Burkholder et al., 2020; De Rijdt et al., 2013; Joshi & Verspoor, 2012). Some of the identified factors that reduced students' physics achievement were students did not get effective teaching method, students believed that physics as a difficult subject, low motivation towards learning of physics, lack of facilities and laboratory equipment to facilitate physics learning, teachers' content knowledge of physics and the like.

Many of these studies indicated that use of inappropriate teaching method is one of the major factors that impaired students' physics learning which resulted low academic performance. From different studies, it was mentioned that common teaching method in secondary school physics classroom is traditional teaching method dominantly which would not enhance students' physics learning and their achievement in the subject (Gunta & Ousman, 2015; Higueras-Herbada et al., 2019; Hussain et al., 2011; Kunkle & Allen, 2016; Negassa, 2014; Sbhatu, 2021; Selcuk et al., 2011; Sulisworo & Suryani, 2014).

To reverse this situation, there is a need to develop instructional strategy that helps students to learn physics and improve their academic achievement. Secondary school students in Ethiopian context faced the new contents of electricity and magnetism such as the contents of electric field, electric potential, magnetic field strength and the like (Dega et al., 2013). Besides, many of the concepts of electricity and magnetism are abstract in nature in which they cannot be directly observed like those of velocity and acceleration of a moving car in mechanics (Li, 2012). Mbonyiryivuze et al. (2019) also indicated that the mathematical formulas are a little bit complex to use them in solving problems in relation to electricity and magnetism. Therefore, from these natures of electricity and magnetism, there has to be a need of using students' prior knowledge and experience for the learning of new concepts and algorithms with a visualized manner for creating mental models through the use of active learning methods. To teach new contents in science by involving learners' prior experience and knowledge, analogical reasoning based instructional strategies were recommended (Gilbert & Justi, 2016; Richland & Begolli, 2016; Ugur et al., 2012).

Other research findings by Rosali (2020) and Suleman et al. (2017) revealed that computer assisted instructions such as use of simulations had a positive effect on improving the quality of classroom lessons. These studies showed that using simulated instructional strategy helps to increase students' participation and interest in doing intellectual activities. The research findings also indicated that simulation assisted teaching methods helps to fosters students' motivation during the lesson presentation and suitable to present abstract concepts using models.

Thus, study was aimed to solve students' problem of physics learning by using simulated analogical reasoning blended with group discussion method with particular to electricity and magnetism domain of physics at secondary school level in Ethiopian context. Therefore, the purpose of this study was to investigate the effect of simulated analogical reasoning blended with group discussion method on students' achievement of physics at secondary school 10th grade level in Ethiopia.

MATERIALS AND METHODS

This study had used a non-randomized pre- and post-test quasi experimental design. This design was suitable due to the reason that the objective of the study was to investigate the effect of simulated analogical reasoning scaffold by group discussion method on secondary school students' achievement of physics. This design is useful to compare differences observed among treatment groups without comparison group by leveling the instructional strategy in different strands and made conclusions only among them (Lappi, 2013). Therefore, the researcher had designed the instructional materials and gave training for the participant physics teachers in which it was believed that teachers' variation can be maintained to some extent. Three different high school found in Debre Tabor town, Amhara Regional State, Ethiopia was selected purposively to test the effectiveness of the designed instructional strategy. The three high schools were found in different corners of the town which are far apart to each other. Students in both schools learn physics as a major subject as designed by the ministry of education curriculum framework (MoE, 2009). Since the total number of 10th grade students, economic and social status of students, and school facilities in the three high school were equivalent, one intact class from each school were selected as participant of the study using a random sampling method. So, in the study a total of 120 students were the sample of the study. Meanwhile, the three groups still were assigned randomly as experimental group 1 or EG 1(n=44), experimental group 2 or EG 2(n=39), and experimental group 3 (n=37) to learn the selected contents of electricity and magnetism domain of physics through analogical reasoning method alone, analogical reasoning scaffold by group discussion method, and simulated analogical reasoning scaffold by group discussion method respectively.

Data were collected by administering electricity and magnetism performance test (EMPT). This instrument was developed by collecting electricity and magnetism standardized tests used by other researchers based on the objective and content coverages by interventions (Li & Singh, 2016; Maloney et al., 2001; Planinic, 2006). Pilot test was made to check its consistencies. Content and face validities of the test instrument was checked by a panel of physics education experts from college of teacher education and

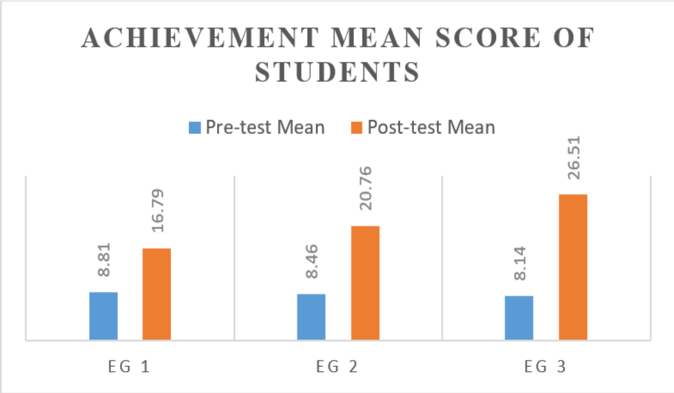

Figure 1. Descriptive statistics of pre- and post-test mean scores by groups

Table 1. Skewness, Kurtosis, and homogeneity of variances for pre-EMPT score

Learning group	Skewness	Kurtosis	Levene's test of homogeneity of variance		
			F	df	p-value
EG 1	-1.02	-.38	2.26	2	.11
EG 2	-1.36	1.62			
EG 3	-1.28	.32			

universities. A reliability coefficient of this instrument was evaluated using KR-20 and the result was found to be at about .76, which is found in the acceptable range.

Before the start of the intervention, pre-test of EMPT was administered for all the three learning groups. The pre-test was used to measure participant students' level about their prior performance in electricity and magnetism part of physics since both had very few and attempts of this branch of physics in their earlier grade 8th level. The next stage of the study was starting the implementation of the intervention which lasted almost after 13 weeks. Both the three groups were covered electric force, electric field, electric potential, electric potential difference, electric current, voltage, resistance, resistors in series and parallel, magnetic poles, magnetic forces, and fields during the intervention time. The first experimental group (EG 1) students had learnt these contents using analogies such as water in a pipe pictures, Newton's law of universal gravitation and water in a tank. The second experimental group (EG 2) students learned the same contents using the same analogies with the addition of group discussion methods. In the first group, the teacher had presented the analogies and students went to map similarities between source and target domains by their own whereas in the second group, once the teacher presented the analogies, students were making mappings by doing activities in a group. The third experimental group (EG 3) students covered the learning of the same contents through the use of simulated analogies which were displayed by the teacher through the use of plasma television and then students were mapping similar attributes between domains in their group discussions. After, the end of intervention, those participant students again took the same EMPT as post-test. The result of both the pre- and post-EMPT scores were analyzed and presented below.

RESULTS

The results obtained through the administration of electricity and magnetism test for all the three groups were displayed and analyzed in the following sections of this paper. The pre- and post-test mean score of EMPT by each group were indicated in **Figure 1**.

From **Figure 1**, the descriptive statistics showed that there was a difference on the pre-test mean score of electricity and magnetism performance among the three groups. Thus, there was a need to check whether the mean difference among groups was significant or not using the appropriate inferential statistics. To do this the assumptions of normality of data via skewness and kurtosis, and assumptions of homogeneity of error variances was checked by Levene's test. The results were indicated in **Table 1**.

From **Table 1**, both the skewness and Kurtosis z-scores were found in the range of ±1.96 which was taken as an acceptable value (George & Mallery, 2019). The results indicated that the pre-test scores of EMPT were roughly approximately normally distributed and hence the assumption of normality was not markedly violated. The homogeneity of error variance was checked by using Levene's test and the result showed that the variance error among the groups was almost the same ($F(2, 117)=2.26$, $p>.05$). Thus, the assumption of homogeneity of variance was not also violated to run one-way ANOVA to check the significance of pre-test mean score of achievement among the three groups.

The one-way ANOVA result above, indicated that there was no statistically significant mean score difference on students' pre-electricity and magnetism test among groups ($F(2, 117)=4.72$, $p>.05$). The result revealed that students in both learning group were assumed to be found on the same level of knowledge of electricity and magnetism domain of physics. Therefore, the difference on the post-test mean score among the groups were taken as the effectiveness of the instructional strategy used by the groups.

Table 2. One-way ANOVA results of pre-EMPT mean scores among groups

	Sum of squares	df	Mean squares	F	p-value
Between groups	9.43	2	4.72	1.13	.33
Within groups	488.56	117	4.18		
Total	497.99	119			

Table 3. Skewness, Kurtosis, and homogeneity of variances for post-EMPT score

Learning group	Skewness	Kurtosis	Levene's test of homogeneity of variance		
			F	df	p-value
EG 1	-.81	.54	1.47	2	.63
EG 2	-.75	1.53			
EG 3	-1.92	-.11			

Table 4. One-way ANOVA results of post-EMPT mean scores among groups

	Sum of squares	df	Mean squares	F	p-value
Between groups	1,903.84	2	951.92	59.58	.000
Within groups	1,869.33	117	15.98		
Total	3,773.17	119			

Table 5. Post-hoc comparison of post EMPT mean scores

Multiple comparison			
Dependent variable: Post-achievements score using Bonferroni			
(I) Learning group	(J) Learning group	Mean difference (I-J)	p-value
EG 3	EG 2	5.74*	.000
	EG 1	9.72*	.000
EG 2	EG 1	3.97*	.000

Note. *The mean difference is significant at the 0.05 level

The post-test result in **Figure 1** showed that there was a difference on the mean score of electricity and magnetism post-test among the groups. Therefore, to check whether the mean score difference among groups was significant or not, the assumptions of normality and homogeneity of variance were evaluated and reported in **Table 3**.

The skewness and Kurtosis z-scores for post-test scores of electricity and magnetism were found in the range of ±1.96, which was taken as an acceptable value (George & Mallery, 2019) as indicated in **Table 3**. The results indicated that the post-test scores of EMPT were roughly approximately normally distributed and hence the assumption of normality was not markedly violated. The homogeneity of error variance was checked by using Levene's test and the result indicated that the variance error among the groups was almost the same ($F(2,117)=1.47$, $p>.05$). Thus, the assumption of homogeneity of variance was not also violated to run one-way ANOVA to check the significance of post-test mean score of achievement among the three groups.

The one-way ANOVA result in **Table 4** indicated that there was statistically significant mean score difference on students' post-electricity and magnetism test among groups ($F(2, 117)=59.58$, $p<.05$). The result indicated that there was a significant mean difference on students' achievement score by at least one of the groups. Thus, to identify which group makes a significant mean difference of the post-achievement score, post-hoc multiple comparison using Bonferroni analysis was used and the results were indicated in **Table 5**.

The post-hoc analysis using Bonferroni indicated that students in EG 3 showed a significant mean score difference on their EMPT as compared with students from EG 2 and 1 ($p<.05$). The experimental group 3 students who were exposed to simulated analogical reasoning scaffold by the group discussion method scored a significantly larger mean (M=26.51, SD= 4.25, n=37) than experimental group 2 students who used analogical reasoning scaffold by the group discussion method (M=20.76, SD=4.10, n=39) and experimental group 1 who treated with analogical reasoning method only (M=16.79, SD=3.67, n=44). The mean difference of the post-electricity and magnetism test was significant with the 95% confidence interval around the difference among group mean was relatively precise with respect to experimental group 2 (3.52, 7.97) and with respect to experimental group 1 (7.55, 11.88). The post-hoc comparison also showed that there was also a significant mean difference on students' post-electricity and magnetism test score between EG 2and EG1 ($p<.05$). The results asserted that students who used analogical reasoning scaffold by group discussion method scored larger mean of electricity and magnetism test (M=20.76, SD=4.10, n=39) than experimental group 1 students who used analogical reasoning method alone for the learning of electricity and magnetism (M=16.79, SD=3.67, n=44). The post-test mean difference between these two groups with the 95% confidence interval around the difference between group mean was somehow precise (1.84, 6.11). Thus, students who used simulated analogical reasoning scaffold with group discussion method showed a larger mean score than students who used analogical reasoning scaffold by the group discussion method followed by the groups who used analogical reasoning method alone. So, the result analysis more favors the effectiveness of using simulated analogical reasoning scaffold by the group discussion method in improving students' achievement in this domain of physics than using analogical reasoning scaffold by the group discussion method and using analogical reasoning method alone.

Therefore, from the result analysis, it was found that using simulated analogical reasoning scaffold by the group discussion method is more effective way of instructional strategy to foster secondary school students' achievement in electricity and magnetism domain of physics than those of analogical reasoning either scaffold by the group discussion method or using it alone.

In addition, from the result analysis, it was found that using analogical reasoning scaffold by the group discussion method was also relatively effective in improving students' achievement in the same domain of physics than using analogical reasoning method alone.

DISCUSSION

The aim of the study was to investigate the effect of simulated analogical reasoning scaffold by the group discussion method on secondary school students' achievement in physics, in particular to electricity and magnetism domains. The finding showed that this instructional teaching method was more effective to improve students' achievement in electricity and magnetism part of physics than using any verbal or textual form of analogical reasoning either scaffold by the group discussion method or using it alone in the physics classroom.

The positive effect of analogy-based instructions was investigated by previous research (Cinyere & Madu, 2014; Didis, 2015; Gokhan et al., 2012; Okoronka & Wada, 2014; Wang et al., 2016). These studies revealed that analogy-based instruction helps students to learn new contents through the use of their own prior knowledge and experiences effectively which ultimately enhances their achievement. In line to this, the simulated analogies scaffold with group discussion method was more effective in improving students learning of more abstract contents of electricity and magnetism by creating visualization environments. The instructional strategy assisted students to learn electric force, electric fields, electric potential, electric current, voltage, equivalent resistance of resistors in series and parallel connections, magnetic fields and its strength and others with linking what they knew before such as using newton's law of universal gravitation between two masses, water flow in a pipe, water in a tank and the like so that they had developed their own mental models about them. Therefore, developing a scientific mental model about the abstract contents of electricity and magnetism helps students to achieve a very good examination marks in the subject.

On the contrary, other previous research findings came up with a different finding that using analogy-based instructions impaired students learning which resulted low achievement (Cruz-Hastenreiter, 2015; Korhasan & Hidir, 2019; You, 2019). These studies indicated that analogies were ineffective due to the reasons that students might have not an experience of using this method, some of the students faced challenges even to see the analogue concept itself, and usually they failed to indicate the point where it stopes working. Of course, many of the analogies used by these researchers were classified under the category of concrete analogy-based instruction which were presented in the form of texts or static pictorial analogies. The textual and static pictorial analogies included in physics textbooks were marginalized, lack enough statements about the limitations of the analogies, and they are not enriching enough with more explanation for extended use and lacks visualization. But this study had come up with presenting the usual and known analogies such as water flow in a pipe analogy in the form of simulations in parallel to the electric circuit simulation and facilitating students' interaction of knowledge construction through the scaffolding of group discussion. The simulated analogies more precisely indicated the breaking point of the analog like the leaking of water when the pip cracks somewhere whereas flow of charges stopped immediately when the wire cuts somewhere in the circuit. In this case, the model of analogy-based instruction presented in the classroom makes both the teacher and students identify the mapped and unmapped attributes and relations between the base and target domains which helps them to take about the problem. Using simulated analogical reasoning scaffold with group discussion method also filled the gap about students' unfamiliarity about the method itself. The model we used initially make the teacher to assess about the adequacy of students' prior knowledge about the analogue. If it is not sufficient enough, the teacher has to make a quick revision about the analogue concept then proceed to the next level of classroom teaching.

CONCLUSION

Using simulated analogical reasoning scaffold by the group discussion method is an effective instructional strategy to improve secondary schools' achievement of the learning of electricity and magnetism domain of physics. The instructional method was very important to create scientific mental models about the abstract contents found in electricity and magnetism in which students can easily recall, classify, analyze, and apply their knowledge stored in their memory to answer questions in examinations ultimately scored a high achievement as compared to using concrete analogical reasoning method scaffold by the group discussion method or alone in physics lessons. The simulated analogical reasoning scaffold by the group discussion method was very effective in capturing the whole attention of students during lesson presentation, makes students more interactive and engaged in the process of mappings which makes them active participants in the way of contributing their own experience and prior knowledge for the construction of knowledge in the classroom society as compared to other mode of analogy based instructional strategies. Finally, the instructional strategy helps students learn from others and succeeded to improve their achievement in the subject.

Due to the effectiveness of simulated analogical reasoning scaffold by the group discussion method on improving students' achievement in electricity and magnetism portion of physics, the researcher recommended that physics teacher can use this method of teaching in other domain of physics such as mechanics, temperature and heat, wave and geometrical optics and others so as to improve their students' achievement. We also recommended other science teachers to use this instructional model in their teaching. Finally, based on the positive effect of this study, we also recommended physics textbook developers and physics curriculum experts to be informed and include simulated analogies in the textbook so that the teacher can used it by blending it with other student-centered teaching methods so as to improve students over all physics achievement at every level of the education system.

Since this study was conducted by taking three different groups from three different high schools, the teacher variation might have its own influence on the result of the study even if trainings about the instructional material was given. So, teacher variation was one of the limitations of this study. The other limitation is that the study was carried out by taking small sample size, if the sample size would be large enough, the result of the study might be different. Therefore, by minimizing these limitations further studies can be done to investigate the effectiveness of simulated analogical reasoning scaffold by group discussion method on students' physics achievement.

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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