

Promoting Students' Academic Self-Efficacy in Chemistry through Teaching Using Molecular Models

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Abstract: This study investigated how students' self efficacy in Chemistry is affected through the use of molecular models as contrasted with the conventional instructional strategies in the topic of Structure And Bonding (SAB). The study was carried out in Khwisero sub-county, Kakamega County, in the republic of Kenya, using quasi-experimental research design, which was implemented via the pretest-posttest with control model. The sample comprised of 309 form two students, from four secondary schools in Khwisero sub-county. The students were selected by the quota sampling method and randomly assigned into two experimental (E1 and E2) and two control (C1 and C2) groups. The experimental groups received instruction in SAB using molecular models alongside the Conventional Methods of Instruction (CMI), while their counterparts in control groups were taught using the CMI only. The Self-Efficacy Questionnaire (SEQ) was created by the researcher, validated and assessed for its reliability, and used to collect the study's raw data. Both descriptive (mean, mean gain and standard deviation) and inferential (one-way ANOVA) analyses were performed on the data, the latter for testing the study's null hypothesis at the 0.05 alpha level of statistical significance. The empirical findings clearly pointed out that the use of molecular models was superior to the conventional methods of instruction in terms of promoting students' self-efficacy in Chemistry. These results have several implications in the way Chemistry ought to be taught at secondary school level, in order for the subject to compete favorably with other sciences in future national examinations.

Keywords: Molecular Model, Self-efficacy, Performance, Structure and Bonding.

INTRODUCTION

In most countries around the world, the main reason why Chemistry is taught at secondary school level is to foster in all learners an interest in the scientific method of obtaining knowledge to help them become innovators and problem solvers. As a consequence, most countries, especially those in the developing world are continually channeling colossal amounts of their budgetary allocations towards technology-related discoveries [1]. In Kenya for instance, this happens through the annual secondary schools science congress competitions, which rewards students who come up with innovations in technology geared towards providing immediate practical solutions to issues facing present day Kenya like renewable energy [2, 3].

However, the quest for attainment of Kenya's vision 2030 has not gone on unchallenged. The major issue plaguing Chemistry education in Kenya currently lies in students' poor performance in the subject during the annual Kenya Certificate of Secondary Education (KCSE) examinations. This predicament has continually troubled the Kenyan education sector from

as far as 10 years ago [1]. Students' low self-efficacy in most abstract topics in the subject is one of the reasons that have been given to account for this worrying predicament [4].

According to Bandura, [5] academic self-efficacy is the belief of a learner that they can successfully perform a task and get the desired outcome. Self-efficacy is perceived as one of the most significant aspects of human behavior that determine whether or not learning activities will be achieved successfully. The higher a learners' self-efficacy therefore, the higher the performance in their academic endeavors [6]. Research reveals that teachers' use of molecular models to demonstrate the concept of bond formation plays a pivotal role in enhancing students' performance in Chemistry, especially when used alongside the CMI [7]. A critical breakdown of students' responses to questions in the theoretical papers of the KCSE in Chemistry reveals that only topics that are abstract in nature are adversely affected [8]. The form two topic of SAB has not been spared either. The latest Kenyan secondary school curriculum stipulates that for this topic to have been taught

successfully, the learner should by the tail end of the topic be able to: - (i) state the significance of valence electrons in bonding, (ii) explain the formation of covalent, metallic and electrovalent bonds, (iii) illustrate diagrammatically the formation of covalent, dative electrovalent bonds, and the Van der Waal's forces (iv) explain the unique nature of metallic bonding, (v) state the effect of intermolecular forces of attraction on physical properties of substances, (vi) distinguish between bond types on the basis of physical properties of substances and (vii) select appropriate materials for use based on bond type, predict the properties of a given substance on the basis of bond present [9]. Apparently, most of these concepts are basically abstract and should therefore be taught very carefully, using an effective and hands-on instructional approach.

The use of molecular models in SAB is one example of an instructional strategy in which the concept of bond formation can be illustrated using colored round balls to represent atoms, and white sticks to represent covalent bonds. This way, students may directly be involved in constructing the bonds, giving acquisition of the said concepts a hands-on approach. Several aspects of learning have greatly been enhanced through the use of molecular models e.g. attitude and achievement of learners [7]. Self-efficacy, which is also an important aspect of academic performance, is an area that might as well be greatly enhanced through the use of molecular models when used in the abstract topic of SAB, or so the researcher believes.

This study was grounded on the Dual Coding Theory (DCT) of information processing. The main tenets of DCT, which has roots in constructivism, posit that cognitive knowledge is processed and stored by human beings in two main forms: - a linguistic and an imagery form [10]. Imagery is expressed in form of mental pictures and physical sensations such as smell, taste, touch, kinesthetic association and sound, while the linguistic form is expressed using words [7, 11]. The theory further suggests that the human cognition consists of two subsystems that process knowledge simultaneously. One subsystem processes verbal information and the other deals with visual objects. While the two subsystems can be activated independently, the DCT asserts that their interrelations and connections allow dual coding of information when used simultaneously.

Molecular models, as were used to teach SAB in the experimental groups of this study, are a form of nonlinguistic (imagery) stimulus representation, which when used alongside verbal material, as was done in both experimental and control groups of this study, lead to very effective learning in abstract concepts like the form two topic of SAB [12]. Generally, studies have

been done to demonstrate that the linguistic form is the most commonly used in classroom instruction by way of lectures and other talk-and-chalk approaches, collectively referred to as the CMI. Usually, teachers talk to students about new content or expect them to read about it. Unfortunately however, this when consistently done, leave it up to learners to generate their own nonlinguistic representation [1]. The teacher uses molecular models to help learners visualize the idea of atoms combining to form chemical bonds through sharing, losing, gaining or donating electrons, hence dual coding of these concepts into a learners' cognitive structure.

The specific objective of this study was to find out if there is any difference in self-efficacy between students who are taught SAB using molecular models and those who are taught using CMI. The null hypothesis (H_0) formulated from this objective was, "there is no difference in self-efficacy between students who are taught SAB using molecular models and those taught using CMI". This H_0 was statistically tested at the 0.05 α -level of significance. The alternative hypothesis was that students taught using molecular models have a higher self-efficacy than those taught using the conventional methods of instruction.

MATERIALS AND METHODS

This study adopted the quasi-experimental research design, using the pretest-posttest with control group as a model. This design was specifically chosen because all units of sampling that had to be incorporated i.e. form two classes, were already constituted. It was therefore unethical to randomly select the required participants, as is required in all experimental studies [1, 13]. However, the selected classes were randomly assigned into experimental (E1 and E2) and control (C1 and C2) groups. Students in all the groups received both pre- and post-test. However, groups E1 and E2 were taught the topic of SAB using molecular models alongside the conventional instruction strategies, while groups C1 and C2 were also taught the same topic, albeit using the conventional methods of instruction. While using this design, the researcher controlled for interaction, a known threat to a study's internal validity by using different schools as experimental and control groups [13]. Selection on the other hand is another potential threat to internal validity of an experimental study and was effectively countered by using schools of the same academic ability. This was achieved by basing selection on previous performance in the Kenya Certificate of Secondary Education examinations for the last two years. Only schools with nearly the same mean score (5 to 7) were included in the sampling frame.

The study was done in Khwisero sub county, Kakamega County, in Kenya. The region was selected

because it is one of the sub counties in the country in which students perform very poorly in Chemistry in the annual KCSE examinations. Quota sampling technique was used to select four secondary schools in the research area, two of which were mixed, one boys' the other a girls' school). This was the case because mixed (co-educational) schools constitute more than half all the secondary schools in the county. Form two students were used because the topic under investigation, which was SAB, is found at this level the Kenyan secondary school syllabus. A total of 309 students and 10 Chemistry teachers were used. The teachers selected were those who were at the time of the study, teaching the selected form two students. This number (sample size of 309) was arrived at basing on the Krejcie and Morgan formula, which deems 309 as the number of participants that would be sufficient to represent the target population of this study, which was approximately 2000 form two students.. The findings of this study could therefore be generalized to all other schools in the research area, which have similar characteristics as those used in this study. The four selected schools constituted the study's research groups in their intact form. The groups were not equal in size because as earlier mentioned, the form two classes that had to be selected were used in their intact form, due to ethical issues that surround research in a school setting, which render full randomization a toll order.

Raw data for this study was collected using the Self-Efficacy Questionnaire (SEQ). This was a closed-ended questionnaire, which had 28 statements, on a five point likert-type scale. Fourteen of these items were favorable (positive), while the other 14 were unfavorable (negative). The entire SEQ was designed by the researcher, through inspiration and guidance from review of related literature. Favorable statements in this questionnaire were scored in descending order i.e. Strongly Agree=5, Agree=4, Undecided=3, Disagree=2 and Strongly Disagree=1, while unfavorable statements therein were scored in the reverse order. To ensure a high completion rate, the researcher produced colored copies of the SEQ. Before being used in the actual study, the SEQ was validated using two educational research experts, who were both asked to critique all items in it and assess for its face and content validity. Comments that were given by the experts were used by the researcher to modify the SEQ, so as to make it more suitable for data collection in the actual study. Reliability of the SEQ was on the other hand assessed using the Cronbach's alpha coefficients for internal consistency method, in which a coefficient of 0.819 was obtained in the pilot study that was carried out two weeks to the actual study. This value implies that the SEQ instrument, if used severally under similar conditions, would produce consistent results. This assertion is deduced from the fact that the co-efficient

obtained was above 0.7 as recommended by George and Mallery [14].

All the research groups were given the pre-test SEQ, followed by intervention that lasted for 19 days. The post-test SEQ was thereafter administered to all the sampled students. The completed questionnaires were coded using SPSS version 21 to facilitate analysis. Data collected was first analyzed descriptively by computing the self-efficacy mean, self-efficacy mean gains and standard deviations for each of the four research groups. The null hypothesis of this study was then tested inferentially using the independent samples t-test and one-way Analysis Of Variance (ANOVA) for pre-test and post-test administrations respectively. Both analyses were done at $\alpha=0.05$, to determine if the self-efficacy mean scores of the groups under comparison differed significantly from each other in terms of academic self-efficacy in chemistry both before and after intervention. One-way ANOVA was used because there were more than three groups in the post-test. All the groups had also been classified basing on only one factor (group type), hence the choice of one-way ANOVA. Independent samples t-test was used because in the pre-test, there were only two groups being compared, experimental as one group and control as the other. Both groups were not related in any way, making independent t-test the most ideal choice and not any other type of t-test. Assumptions of these two parametric tests were assessed beforehand; normality of the self-efficacy scores was assessed using the Kolmogorov-Smirnov test, while homogeneity of variances of the self-efficacy scores was assessed using the Levene's test [1, 13]. Both tests yielded non-significant p-values (values greater than 0.05, the set alpha). These values meant that the data collected by the SEQ was fit for analysis, using these two parametric tests, without any possibility of committing type one and or type two statistical errors. Parametric tests also demand that the research groups used should be independent of each other. This important assumption was deliberately not assessed, because it had already been taken care of by the research design in the sense that only intact classes were selected and used for the study, for earlier explained reasons. Different schools were used as experimental and control groups also for this reason. None of the form two students in the research area therefore stood the possibility of being in more than one research group at the same time as the treatment in all groups was carried out concurrently.

RESULTS AND DISCUSSION

Results of the descriptive analysis of the sampled students' self-efficacy scores obtained before and after intervention, using the SEQ were as presented in Table 1.

Table 1: Means and standard deviations of students' self-efficacy scores

GROUP	PRE-TEST		POST-TEST		MEAN GAIN
	MEAN	STD. DEV	MEAN	STD. DEV	
E1 (N=85)	65.9	6.50	88.8	6.91	22.9
E2 (N=68)	66.8	4.20	86.9	5.88	20.1
C1 (N=75)	63.9	4.80	66.6	6.01	2.70
C2 (N=81)	64.6	6.70	65.5	4.07	0.9
COLLECTIVE (N=309)	65.3	5.55	77.0	5.72	11.2

An examination of Table 1 reveals that while the collective mean for the entire sample was 65.3, group E2 had the highest mean of 66.8, while group C1 had the lowest mean of 63.9 marks. The range between the highest and lowest mean score was therefore of 2.9 marks in the pre-test self-efficacy mean scores. In the post test however, the Table shows that while the collective mean score for the entire sample was 77.0, group E1 had the highest mean of 88.8 while group C2 had the lowest mean of 65.5, a bigger margin of 23.3 when compared to the pretest analysis. It can also be pointed out from this Table that both experimental groups obtained self efficacy mean scores higher than the collective mean while the control groups obtained

self-efficacy mean scores lower than the collective mean. We can see from the Table also that even though all the groups had a positive deviation in self-efficacy mean score from pretest to posttest, the experimental groups had higher gains than the control groups.

To find out whether or not the selected students were statistically at the same entry level in terms of self-efficacy at the initial stage of the quasi experiment, independent samples t-test was used to compare the pre-test mean scores of the experimental (combined) and control (combined) groups, whose results were as shown in Table 2.

Table 2: Independent samples t-test (2 tailed) on pre-test self-efficacy scores

		Levene's Test for Equality of Variances				
		F	Sig.	t	df	Sig.
Score	Equal variances assumed	7.96	.748	3.323	308	.799
	Equal variances not assumed			3.323	308	.799

The Table shows that Levene's test for equality of variances yielded a non-significant f-value [F = 7.96, p =.748 at $\alpha = .05$], which implies that the variances in the pretest self-efficacy scores between the control and experimental groups were homogenous. Parametric testing was therefore appropriate for analyzing the self efficacy scores, going by this assumption of equal variances. As the Table further reveals, there was no statistically significant difference in pre-test self-efficacy scores between students in the control groups and those in the experimental groups [

(308) = 3.32, p =.799 at $\alpha = .05$] since the p-value obtained is greater than the set alpha level. This implies that the sampled students were statistically at the same entry level with respect to self-efficacy in Chemistry before intervention.

To establish whether or not the students' self-efficacy differed between the four groups after intervention, one-way ANOVA was performed on the students' post-test SEQ scores. Results of this inferential test were as presented in Table 3.

Table 4: One-way ANOVA on post-test self-efficacy scores

SOURCE	d.f	SS	MS	F	Sig.
Between groups	3	37,320.297	12,440.099	367.1*	0.000
Within groups	305	10,325.405	33.854		
TOTAL	308	47,645.702	-		

*Significant at $\alpha = 0.05$

As Table 4 indicates, there was a statistically significant difference in the post-test mean scores between the four groups under comparison [F (3, 305) = 367, p < .001 at $\alpha = .05$]. This is because the p-value obtained is less than the set alpha. This output implies that the posttest self-efficacy mean score of at least one of the four groups under comparison differed significantly from the others. To determine exactly which group(s) were responsible for this difference, post hoc testing was mandatory, which was performed using the Tukey's Least Squares Difference (LSD) and the outcome was as presented in Table 4.

Table 4: LSD post hoc test p-values for post-test self-efficacy scores

	E1	E2	C1	C2
E1		0.675	0.01*	0.04*
E2	0.675		0.003*	0.008*
C1	0.01*	0.003*		0.522
C2	0.04*	0.008*	0.522	

*significant at $\alpha=0.05$

The Table reveals that the post test self-efficacy mean scores of the experimental groups (E1 and E2) did not significantly differ from each other, and so was the case with control groups (C1 and C2). However, the Table points out that the mean scores of the experimental groups significantly differed from those of control groups in favor of the former. This result, when interpreted together with that obtained from the earlier mentioned descriptive analyses clearly suggest that the study's experimental groups, which were taught SAB using molecular models were superior to control groups, with regard to self-efficacy after intervention.

The null hypothesis (H_0) of this study as earlier stated was, "there is no difference in self-efficacy between students who are taught SAB using molecular models and those who are taught using the Conventional Methods of Instruction". The study however found a statistically significant f-ratio on the four post-test self-efficacy mean scores, which is contrary to the assertions of this null hypothesis. The null hypothesis of this study was consequently rejected since the empirical evidence arising from both descriptive and inferential statistics of this study clearly prove the contrary.

It can now be asserted from this outcome that using molecular models in the teaching and learning of structure and bonding improves self-efficacy of form two students when used alongside the conventional methods of instruction. These findings are in agreement with those of the study by Mulavu *et al*, [7], whose Kenyan study that used a similar methodology revealed that the use of molecular models had a stronger influence on students' academic performance in Chemistry when compared to the use of traditional instructional approaches alone.

CONCLUSION

On the basis of data collected in this study and the empirical evidence provided by the study's statistical analyses, it is hereby concluded that the use of molecular models to teach the form two topic of structure and bonding significantly improves students' self-efficacy in the topic when compared to the use conventional approaches to instruction. This positive effect of molecular models on students' self-efficacy in Chemistry is attributed to the fact that it was a hands-on

experience for all the learners, who were all able to visualize all abstract concepts therein. Teachers of Chemistry in Kenya should therefore embrace fully the incorporation of molecular models in the topic, so as to solve the current performance crisis that has befallen Chemistry education in the country for the past ten years.

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