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Enhancing Kenyan Secondary School Students' Performance in Chemistry Using Retrieval Based Concept Mapping

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Abstract:
The aim was to determine if performance in chemistry can be improved by use of Retrieval Based Concept Mapping. The objectives were to compare Concept Mapping and Retrieval Practice and also find out which Retrieval Practice activity between Free Recall and Concept Mapping is best in enhancing performance and retention of chemistry concepts. A quasi-experimental design was used with 103 participants. Three test instruments were administered to participants as Chemistry Pretest, Chemistry Achievement Test and Chemistry Retention Test. Results showed that Retrieval Practice and Concept Mapping are both effective strategies in enhancing performance and retention of chemistry concepts but Retrieval Practice is better than Concept Mapping. This study also found that Concept Mapping when used as a Retrieval Practice activity is superior to Free Recall. The study recommends that teachers and learners embrace the use of Retrieval Based Concept Mapping to enhance performance in chemistry.

Keywords: *Retrieval practice, concept mapping, information retention, chemistry*

1. Introduction

Chemistry educators suggest that for the subject to be well learnt, learners should be able to make conceptual connection between representations and also develop an understanding of underlying concepts (Kilic & Cakmak, 2013). This position is supported by Ajaja (2011), Boujaoude & Attieh (2007) and Barchok (2011) among others who embrace the idea of meaningful learning and active involvement of the learner in the learning process. One way of attaining this is through practical work. Chemistry is inherently a practical subject where scientific concepts are developed through practical investigation by experiments (Njagi & Njagi, 2015). However, effective implementation of chemistry practical work is hampered by lack of sufficient laboratory resources in most Kenyan secondary schools. The other challenge manifested is lack of technical knowhow by teachers on planning, structuring and execution of chemistry practical lessons (Ituma & Twoli, 2015; Mwangi, 2016). These challenges call for the need to have alternative approaches to active involvement of learners for successful implementation of chemistry curriculum. A number of teaching models have been designed in a bid to improve the status of chemistry instruction. Such carefully planned instructional strategies include: 'the Learning Cycle' (Opara & Waswa, 2013); 'Secondary School Chemistry Investigative Practical Work' (Ituma & Twoli, 2015); 'Cooperative Mastery Learning Approach' (Keter, Barchok & Ng'eno, 2014); 'Computer Aided Strategy' (Julius, 2018) and 'Computer Based Simulation' (Mihingo, Wachanga & Anditi, 2017).

Concept mapping and Retrieval Practice are active learning strategies that have been found to not only promote meaningful learning but also enhance retention of learnt concepts. In chemistry, concept mapping is meant to address the problem of linking the multidirectional nature of concepts (Jack, 2013). According to Sket and Glazar (2005), this strategy requires the learner to identify key concepts and show how they are interrelated, allowing thinking in multiple directions. Researchers have also established that concept mapping helps learners to retain learnt concepts (Ajaja, 2011; Jack, 2013; Odom & Kelly, 2000; Ikedolapo & Adetunji, 2009; Yekta & Nasrabadi, 2004).

Retrieval Practice is another active learning strategy that has been found to promote meaningful learning (Smith, Whiffen & Karpicke, 2016) and enhance retention of learnt concepts (Karpicke & Bauernschmidt, 2011; Smith, Roediger & Karpicke, 2013). A wealth of past research gives consistent findings which support the idea that practicing retrieval promotes long term retention more than does spending equivalent time repeatedly studying. To practice retrieval simply means to purposefully reconstruct knowledge (Karpicke & Blunt, 2011) by repeatedly retrieving information from memory. This act alters memory (Karpicke, 2017) thus improving future retrieval of that knowledge and other related information (Karpicke, 2018). The process of retrieval is not neutral for learning (Smith, Blunt, Weinstein & Karpicke, 2016), instead every time information is retrieved there is some change that occur which improves one's ability to retrieve and reconstruct that knowledge in future. It is important to note that concept mapping and retrieval practice techniques are not mutually exclusive and researchers have investigated the efficacy of combining them.

Even though extensive research has been conducted on Retrieval Practice, there is still no commonly agreed upon theoretical explanation of the mechanisms underlying the process. Two commonly fronted theoretical accounts: the episodic context and the elaborative accounts seem to be inconsistent yet they intend to offer an explanation about the same phenomena. Proponents of the elaborative account propose that the process of retrieving information from memory

makes the memory trace to be elaborated by increasing the number of retrieval cues making it likely that information will be successfully retrieved in future (Roediger & Butler, 2011). For Carpenter (2009), in an attempt to retrieve target information from memory, several semantically related information is activated leading to elaboration during initial retrieval which enhances retention on subsequent tests (Lehman et al, 2014). Retrieval may involve deep, elaborative processing and therefore Retrieval Practice may operate just like any other elaborative study task (Karpicke & Smith, 2012).

On the other hand, the episodic context account proposed by Karpicke, Lehman and Aue (2014) attributes the benefits of Retrieval Practice to the process of recollecting the context of a prior learning episode (Karpicke & Zaromb, 2010). Context reinstatement is the underlying mechanism of this account and it is said to occur during retrieval by creating a unique set of context features that becomes associated with successfully retrieved items. Context representation is updated to include multiple features from both past and present contexts which can be reinstated later on to accomplish retrieval (Karpicke, Lehman & Aue, 2014). In comparing key tenets of the two accounts, it can be noted that they both attribute the benefits of Retrieval Practice to the size of the search set and the strength of cues that aid memory. Whereas Retrieval Practice restricts the size of the search set and reduces the number of memory cues as predicted by the episodic context account, elaboration expands the search set and increases the number of cues that aid memory.

Key questions arise at this point with regard to the two theoretical explanations of Retrieval Practice: One concern of Lehman et al., 2014 is that if semantic elaboration is the underlying mechanism responsible for the benefits of Retrieval Practice, why then is it that conditions that directly bring about this type of elaboration such as Concept Mapping do not produce performance similar to Retrieval Practice conditions. Secondly, if elaboration is not only responsible for Retrieval Practice but also for the process of Concept Mapping, is it possible that a combination of these two techniques can yield benefits superior to those of using Retrieval Practice or Concept Mapping alone?

1.1. Statement of the Problem

The problem to be addressed by the present study is that of poor performance in chemistry by secondary school learners. Students have consistently failed in science subjects as depicted in summative examinations' results in Kenya (Wanzala, 2018). If this trend continues then 'Vision 2030', Kenya's economic development blueprint, is likely not to be realized. This is owing to the critical role of science subjects as prerequisites to the study of medicine, pharmacy, engineering and other technological courses. The problem has mainly been attributed to inappropriate instructional techniques which has prompted researchers and educational stakeholders to design and recommend the use of teaching and learning models aimed at improving chemistry instruction.

The government of Kenya has put in place measures to improve science and mathematics teacher's pedagogical skills through an in-service teacher training program referred to as 'Strengthening Mathematics and Science in Secondary Education' (SMASSE). Despite such concerted efforts, learners still continue to show difficulties in understanding chemistry concept. This study therefore sought to address the problem by investigating the efficacy of a teaching and learning model dubbed Retrieval Based Concept Mapping (RBCM) in supporting conceptual understanding and long term retention of chemistry concepts.

1.2. Justification of the Study

In any science educational practice, students are faced with a challenging requirement to learn and then retain a very large volume of complex information (Dobson, 2013) to be reproduced later especially in an exam. Despite the immense challenges presented by the above-mentioned goal, relatively little research has investigated the direct effects of long-term retention of particular educational interventions (Larsen, Butler & Roediger, 2013). While benefits of Retrieval Practice in educational practices are almost beyond contention, there is need to understand how well it compares with other methods of active learning (Larsen, Butler & Roediger, 2013) yet few studies (Karpicke & Blunt 2011; Blunt & Karpicke 2014) provide this kind of comparison. Furthermore, Smith and Karpicke (2014) are of the opinion that if Retrieval Practice is to be implemented in classrooms, then it is important to know which Retrieval Practice formats are most effective for promoting meaningful learning.

Very few studies have investigated Retrieval Practice strategy in the context of an actual class. Most of such studies have been conducted outside classroom settings (Dobson, 2013) and the kind material used has been mostly word lists or brief texts which do not reflect a typical classroom learning condition. Of key concern is that none of previous studies has investigated Retrieval Practice with chemistry material which is unique given the fact that the concepts are complex and interoperate at three levels of thought: macroscopic, microscopic and symbolic. The current researcher is keen to find out if the benefits of Retrieval Practice hold for such material with high element interactivity and in an actual classroom setup that depicts a characteristic educational setting.

2. Research Methodology

Quasi-experimental design was employed for this study. According to (Ary, Jacobs, Razavieh & Sorensen, 2006) this is a type of experimental design where participants are not randomly assigned to their respective study groups. The researcher found this design appropriate since it allowed data to be generated and a comparison of three intact classes to be made without a change in class teaching routine. The type of quasi-experimental design used was the non- equivalent comparison group pretest-posttest. It was deemed most fitting in a typical school situation because routines were not disrupted nor classes reorganized to fit the research processes. The design consisted of

three comparison groups: Concept Mapping (Group 1), Retrieval Practice by Free Recall (Group 2) and Retrieval Practice by Concept Mapping (Group 3) which formed the independent variables. Dependent variables were performance in chemistry and information retention.

2.1 Study Population, Sample Size and Sampling Procedure

Target population consisted of form three students at Turkana Girls' Secondary School from which a sample of one hundred and three students (103) was drawn. The experimental groups for the study were three intact classes at the school (TGSS) which is located in Loima sub-county, Turkana County, Kenya. One of the classes had 33 students another had, 34 students and the third stream had 36. The average age of the classes was 17 years old. According to Fraenkel & Wallen (2010), a minimum of 30 individuals per group is recommended for experimental research. Similar studies have used sample sizes ranging from 32 (Blunt & Karpicke, 2014), 47(Larsen, Butler & Roediger, 2013) to 80 (Karpicke & Blunt, 2011).

2.2. Research Instruments

Chemistry Pretest (C.P.T), Chemistry Achievement Test (C.A.T) and Chemistry Retention Test (C.R.T) were the instruments used. The instruments were developed by the researcher and administered to participants as tests. Test items in all the instruments comprised of concepts drawn from the three-week instructional material on the topic 'Organic Chemistry I'.

2.3. Data collection Procedure

The study was conducted over a nine- week period during the second term of the Kenyan secondary school calendar year. The experiment period was divided into three parts; the first spreading over one week during which participants in their respective groups were introduced to experimental treatment learning conditions basing on the content of a previously covered topic (The Mole). This was meant to train participants on key aspects of Concept Mapping, Retrieval Practice by Free Recall and Retrieval Practice by Concept Mapping. Experimental Group One participants were introduced to Concept Mapping and guided on how to construct a concept map following a step by step procedure adopted from Kilic and Cakmak (2013). Participants in experimental Group Two and Three were trained on how to practice retrieval either by free recall (Group Two) or by drawing Concept Mapping in the absence of material being studied (Group Three). The second part of the experiment was a three- week instructional period where all groups were taught Organic Chemistry concepts following an instruction schedule prepared in advance. The classes met five times a week for forty minutes of instruction (four lessons) and one eighty minutes long double lesson. At the end of the instruction period, participants in all groups sat for a C.P.T to assess how much Organic Chemistry concepts they had learnt from the instruction sessions. In the last part of the experiment, the groups met for three revision sessions in one week with each session lasting one hour. During the sessions, each student was provided with a list of key concepts guided by a focus question for a particular content area to be reviewed. They were also availed with summarized Organic Chemistry notes for each focus area that was to be reviewed. Participants in the elaborative Concept Mapping condition reviewed Organic Chemistry text in an initial twenty- minutes study period. They were then directed to spend the next twenty minutes creating concept maps on a sheet of paper while referring to the text and reviewing their maps to include all the details from the text in their maps. The group's teacher supervised compliance with these instructions.

In the free recall Retrieval Practice condition, students studied Organic Chemistry text in an initial study period and then practiced retrieval by recalling as much of the information as they could on a free recall test. After studying text for ten minutes, they were told to recall and write down as much of the information from the text as they could in any order they chose. The recall test lasted for twenty minutes and thereafter they re-read the text in another ten-minute study period and recalled it again in another twenty- minutes recall period. Text materials were withdrawn from participants after each study period so that they had no source to refer from during recall. The third group's treatment involved practicing retrieval by Concept Mapping. Here, participants were required to practice retrieval following the same procedure as that of experimental group two.

However instead of engaging in free recall, they were to draw concept maps just like those for experimental group one, but without referring to text being reviewed a. The duration of initial text study period and for constructing concept maps was identical to that in the elaborative Concept Mapping condition. Overall, the total amount of learning time was equal in the three comparison groups.

One week after the treatment period, participants in all groups took a C.A.T consisting of items from the entire instruction material. This post- test was meant to measure the extent of the treatment effect on participants. Three weeks after treatment, a C.R.T was administered to participants in the three groups to measure the level of retention of learnt material. A retention interval of three weeks was chosen arbitrarily without a specific criterion being followed. The researcher was however informed by previous related research work. At the end of each revision session, each participant's review sheet of paper was collected and assessed by a team of chemistry teachers. Constructed concept maps were rated basing on a scoring rubric adopted from Kilic and Cakmak (2013).

3. Results, Analysis and Discussion

3.1. Pre-treatment Examinations Scores

In order to ascertain equivalence of the three treatment groups at the outset, participants' performance in past four chemistry examinations were analyzed and the results for each group's average score are shown in Table 1

Variable	Experimental Group	N	Mean	Std. Deviation	H-value	Df	P-value
Pre-treatment Examination Scores	1	33	52.39	13.33	.328	2	.849
	2	34	52.09	12.69			
	3	36	51.11	13.02			

Table 1: Descriptive Statistics and Kruskal- Wallis H Test for Pre-Treatment Examinations Scores per Group

The above results (H (2) =.328, p =.849) show that the three treatment groups did not differ significantly in their pre- treatment chemistry examination scores. This implies that the three groups were almost similar in terms of the way they acquired chemistry concepts and hence similar performance ability in chemistry.

3.2. Pretest Scores

After being taught Organic Chemistry concepts, participants in all groups were given a Chemistry Pretest (CPT) which comprised of test items from the entire topic taught. The pretest was meant to assess the level to which they had acquired and understood the concepts taught. Table 2 shows a summary of how the three groups performed on the pretest.

Variable	Experimental Group	N	Mean	Std. Deviation	H-value	Df	P-value
Pretest Scores	1	33	13.3	2.378	4.409	2	.110
	2	34	13.2	2.754			
	3	36	14.3	3.086			

Table 2: Descriptive Statistics and Kruskal-Wallis H Test of Pretest Scores

The above results show that the Retrieval Practice with Concept Mapping group (group 3) had the highest performance on the pretest (Mean =14.3, Std. Dev= 3.1). Performance of the other two groups in the pretest was almost identical (Mean= 13.3, Std. Dev =2.4) and (Mean= 13.2, Std. Dev= 2.7) for the Elaborative Concept Mapping and Retrieval Practice by Free Recall groups respectively. Kruskal- Wallis H test results indicate that the difference in performance among the three groups on the pretest was not significant (H (2) =4.409, p =.110) and therefore it was concluded that the groups were near identical in terms of performance on the pretest. This finding corroborates the earlier outcome to the effect that the three groups were almost equivalent in acquisition of chemistry concepts. Concerns about existence of group differences with respect to academic ability of participants before exposure to treatment were somehow allayed.

3.3. Revision Sessions Scores

Treatment procedures geared towards testing hypothesis entailed subjecting participants to different study techniques basing on Organic Chemistry concepts taught earlier. Material was fitted into three study units and apportioned to three revision sessions. The aim was to find out which revision strategy would yield the greatest benefits for learners to attain and retain chemistry concepts. During revision sessions, each participant was required to generate idea units from the materials revised in a session in line with the study strategy for their groups. The proportion of idea units produced by a participant was assessed using a specified criterion and recorded. Table 3 provides a summary of the average idea units produced per group during the revision sessions.

Variable	Experimental Group	N	Mean	Std. Deviation	H-value	Df	P-value
Revision Session Scores	1	33	7.88	1.36	17.925	2	.000
	2	34	7.97	1.03			
	3	36	6.81	1.17			

Table 3: Descriptive Statistics and Kruskal- Wallis H Test of Average Idea Units Generated During Revision Sessions

The results show that on average, the Retrieval Practice by Free Recall group generated the highest proportion of ideas during revision sessions (Average = 8.0, Std. Dev. = 1.02) followed by the Elaborative Concept Mapping group(Mean=7.9,Std.Dev=1.4).The Retrieval Practice by Concept Mapping group had the least proportion of idea units produced (Average = 6.9, Std. Dev= 1.2). A further analysis was done to determine the level of significance of the observed differences in revision session scores. Kruskal -Wallis H test was done and the outcome indicates that the proportion of ideas generated during revision varied significantly among the three groups (H (2) =17.925, p=.000). From these findings, it was concluded that during revision sessions involving Organic Chemistry concepts, participants in the Retrieval Practice

by Free Recall group were able to generate the highest proportion of ideas while the Retrieval Practice by Concept Mapping group participants generated the least number of idea units.

3.4. Chemistry Achievement Test Results

After treatment, participants were subjected to a Chemistry Achievement Test (CAT) which was meant to measure the extent of the treatment effect on participants. Results in Table 4 show that the Retrieval Practice by Concept Mapping group benefited the most from the treatment procedure (Mean=17.67, Std.Dev. = 3.3), followed by the Retrieval Practice by Free Recall group (Mean = 17.35, Std. Dev. =2.9). The Elaborative Concept Mapping Group performed the least on the achievement test (Mean = 16.55, Std. dev. = 2.6).

Variable	Experimental Group	N	Mean	Std. Deviation	H-value	Df	P-value
C.A.T Scores	1	33	16.55	5.54	2.194	2	.334
	2	34	17.35	2.86			
	3	36	17.67	3.31			

Table 4: Descriptive Statistics and Kruskal-Wallis H Test of Chemistry Achievement Test Scores per Group

There was no significant difference in the average C.A.T scores among the three experimental groups (H (2) =2.194, p=.334). In order to ascertain how individual participants had gained from the revision sessions, pretest scores were subtracted from CAT scores to compute an approximate gain for each participant as shown in Table 5.

Variable	Experimental Group	N	Mean	H-value	Df	P-value
Average gain from Revision	1	33	3.2	2.000	2	.368
	2	34	4.1			
	3	36	3.4			

Table 5: Average Gain from Revision Sessions per Group

It was observed that on average, each participant in the Elaborative Concept Mapping group Gained 3.2 Score Units from the revision sessions which was the least compared to 3.4 and 4.1for the Retrieval Practice by Free recall and the Retrieval Practice by Concept Mapping groups respectively. A further analysis revealed that there was no significant difference in individual participants' gain from revision sessions among the three treatment groups. This outcome confirms the earlier finding that the groups achieved an almost similar performance in the C.A.T.

3.5. Chemistry Retention Test results

The present study sought to determine which of the three treatment procedures was more effective in enhancing learners' retention of chemistry concepts. A Chemistry Retention Test (CRT) was given three weeks after treatment to measure how much ideas units would be recalled by participants in each group. Results obtained favor the Retrieval Practice by Concept Mapping group which had the highest average idea units recalled ((Mean=17.3, Std.Dev. = 3.3). Elaborative Concept Mapping group scored the least on the retention test ((Mean=14.6, Std.Dev. = 2.3) and for the Retrieval Practice by Free Recall (Mean=16.7, Std.Dev. = 3.6) (see Table 6)

Variable	Experimental Group	N	Mean	Std. Deviation	H-value	Df	P-value
C.R.T Scores	1	33	14.45	2.36	15.037	2	.001
	2	34	16.68	3.63			
	3	36	17.25	3.26			

Table 6: Summary of Average Chemistry Retention Scores

A Kruskal- Wallis H test for equality of means whose results (H (2) =15.037, p=.001) show that the difference among the groups in performance on recall test was indeed significant.

3.6. Summary

Table 7 provides a summary of findings by ranking the average scores for each experimental group on all the sets of data analyzed in this chapter.

Experimental Group	Pre-treatment Scores	Pretest Scores	Revision Session Scores	CAT Scores	CRT Scores
1	1(52.4)	2(13.3)	2(7.9)	3(16.5)	3(14.5)
2	2(52.1)	3(13.2)	1(8)	2(17.4)	2(16.7)
3	3(51.1)	1(14.8)	3(6.9)	1(17.7)	1(17.3)

Table 7: Position on Ranked Average Score for Various Tests

From Table 7 the three treatment groups were apparently equal on the outset of the experiment in terms of acquisition of chemistry concepts. This is evidenced by the almost identical pretreatment scores across the groups. Additionally, the pretest scores confirm that the groups were near equivalent and that there was no significant difference in chemistry performance ability among them. This meant that the groups were homogenous hence suitable for the study. The outcome of revision sessions indicates that the RBCM (group 3) had the least average score but scored the highest on both the CAT and CRT. Another pattern observed from the summary is that apart from the pretest, the ECMG was inferior to both RPFR and RBCM groups in all the other tests. This implies that Retrieval Practice as a study skill was more superior to elaborative Concept Mapping in enhancing performance and retention of Organic Chemistry concepts. Between free recall and Concept Mapping as Retrieval Practice activities, it was found that the RBCM group scored highest in pretest, CAT and CRT compared to RPFRG. It can be concluded that Concept Mapping was a better Retrieval Practice activity than Free Recall in the study of Organic Chemistry material by form three students at TGSS.

4. Findings and Discussions

The present study found out that students who studied Organic Chemistry concepts by Retrieval Practice scored better in the CAT and the CRT compared to those who studied by elaborative Concept Mapping. The results show that Retrieval Practice is better in enhancing achievement and retention of information than Concept Mapping when used to study Organic Chemistry concepts. These findings are in agreement with the outcome of a related study by Karpicke and Blunt (2011) in which retrieval practice was found to produce more learning than elaborative studying with concept maps. Similar results were obtained in a study by Larsen, Butler and Roediger (2013) where it was concluded that repeated testing is generally more effective than generating self-explanations (an elaborative study technique) in producing superior long-term retention and transfer of knowledge.

The second objective was to find out which Retrieval Practice activity between free recall and Concept Mapping was more superior to the other in terms of fostering performance and retention of chemistry concepts. Results obtained in the current study indicate that learners who practiced retrieval by Concept Mapping performed significantly better than their colleagues who practiced retrieval by free recall. This finding suggests that Concept Mapping as a retrieval practice activity is better than free recall. The outcome differs from that obtained in a similar study by Blunt and Karpicke (2014) which discovered that practicing retrieval either by concept mapping or by writing the material in paragraph format were both equally effective in enhancing long term retention of information. The outcome of revision sessions indicates that the RBCM group had the least average score among the three groups. A further analysis of the amount of gain from the revision session scores revealed that the RBCM group had the highest amount of gain from treatment as measured by the difference between the CAT and revision session scores.

The implication of these findings is; the group that generated the least proportion of ideas during study sessions benefited the most from those sessions. The elaborative concept mapping group had the least gain despite doing well during revision. Although the difference in learning gain between the groups was not significant, these results seem to approve a suggestion by Karpicke and Smith (2012) that elaborative studying improves initial encoding when it occurs prior to the first recall of an item. This means that there was no significant learning with regard to items that had been successfully retrieved during the pretest and this seems to explain the small learning gain by the Elaborative Concept Mapping group. On the other hand, the discovery that the group with the least proportion of ideas generated during study sessions ended up producing the best result on both the CAT and RAT could be linked to the difficulty inherent in encoding and retrieving knowledge which according to Larsen, Butler and Roediger (2013) leads to more durable learning. Lehman et al (2014) in supporting the same idea allude that retrieval tasks which provide the fewest cues yield the greatest benefit because information is readily available requiring an extensive search of memory which leads to most elaboration. In general, the pattern of results obtained in the present study seems to support the constructive retrieval hypothesis whose key tenet is that retrieval is most successful if it involves constructive elaboration of the material being learnt. Basing on the retrieval hypothesis, Endres, Carpenter, Martin, and Renkl (2016) encourage the use of teaching and learning tasks that combine elaboration and retrieval.

5. Conclusions and Recommendations

The study revealed that Retrieval Practice is a better study technique compared to Concept Mapping in supporting achievement in chemistry and retention of learnt concepts. Moreover, Concept Mapping as a format to implement Retrieval Practice during study is more superior to Free Recall in terms of enhancing achievement and retention of chemistry concepts. It can therefore be concluded that Retrieval Based Concept Mapping (RBCM) is an effective study strategy that can help learners to achieve better and retain and retrieve chemistry concepts compared to conventional study techniques. From the aforementioned conclusion, learners and teachers of chemistry are encouraged to adopt RBCM study technique as one way of improving performance in the subject. CEMASTEA should consider adopting RBCM as a teaching and learning model to be incorporated in SMASSE training for teachers of science.

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