International Journal of Education, Learning and Development
Vol. 12, No.2, pp.99-113, 2024
Print ISSN: 2054-6297(Print)
Online ISSN: 2054-6300 (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development-UK

Facilitating Academic Gains with Artifacts of Learning: Effect Concept Mapping on Performance in Cellular Respiration

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doi: https://doi.org/10.37745/ijeld.2013/vol12n299113 *Published February 15, 2024*

Citation: Laar S.M., Azure J.A., Wilmot D., and Ayimbila E.A. (2024) Facilitating Academic Gains with Artifacts of Learning: Effect Concept Mapping on Performance in Cellular Respiration, *International Journal of Education, Learning and Development*, Vol. 12, No.2, pp.99-113

ABSTRACT: *Biological concepts like cellular respiration are abstract concepts that students struggle to understand in Ghana and worldwide. Biological concepts like cellular respiration are abstract concepts that students struggle to understand in Ghana and worldwide. Research suggests that positive gains in student understanding can be achieved through interactive and visual learning tools like concept maps. With that in mind, this study explored the effect concept map formation on students' academic performance at the Ghanaian senior high school level in the concept of cellular respiration. A sample size of 100 students were used for the study. Pre-test, post-test non-equivalent control group design was adopted for the study. Two intact classes were used in this study, one designated as control, receiving standard lecture-based instruction, and the other utilizing concept maps. After the intervention, post-test scores of the students revealed a statistically significant difference between the experimental and control groups. Specifically, the group that used concept maps performed significantly better than the control group, with a large difference in their scores. Furthermore, after the intervention, the concept maps allowed for*

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specific analyses and tracking of the students' understanding, proving its value as a formative assessment tool. The results suggest that concept mapping can be a useful tool in improving students' performance and track learners understanding, gaps and misconceptions in biology topics like cellular respiration.
KEYWORDS: concept mapping, respiration, conventional method, academic performance

INTRODUCTION

Education is viewed as the cornerstone and base of advancement when it comes to how the economy and our educational system as a whole run, with secondary education acting as a pivot. Biology has long been recognised as an important field of study for driving the economic and technological transformation in any society. Hence, the subject Biology is very critical to the betterment and advancement of humanity and his environment. Human survival on this planet, and the development of any nation will forever depend on science and technology (Nyavor & Seddoh, 2006). Biology is devoted to the study of living organisms and life. These include plants, animals and microorganisms. Human beings cannot live successfully on this planet without the proper understanding of how the structures of organism functions, and the interaction of organisms among themselves and their environment.

The reason for teaching biology is to provide explanation of the living world, using scientific principles. Teaching of biology also helps to introduce some skills into the learners. Examples of these skills include the ability to observe, take measurements, formulate hypothesis, record data and interpret results, and so on. Biology further equips students to undertake more studies and research areas that are important for the betterment of humanity. Examples of such vital areas includes the laboratories, industries, agriculture, horticulture, health care, information science etc. Teaching of biology provide the students with the requisite ability to think critically, make decisions that are meaningful and the ability to solve real-life problems (Nyavor & Seddoh, 2006). Over the years, teaching was just simply the process of passing on knowledge from the knowledge bearer (the teacher) to the student, until new philosophers of science introduced modern methods of teaching, by rejecting the long-standing collective view of scientific knowledge. This have made teaching more significant and meaningful to the learner (Ackerman & Eden, 2001). The social constructivist viewed the process of learning to be an active engagement or activity which brings out the principles, concepts and facts for the students, as they themselves goes through such process or activity.

A number of teaching strategies have been derived for a better lesson delivery of science lessons to students in the classrooms. Even though the strategies may be learner-centered, they may

encourage rote learning of science concepts. Memorization of whole passages from science textbooks and rote learning does not contributes much in the acquisition of knowledge and therefore does not enhance creative thinking and novel problem-solving abilities in learners.
The issue about concept mapping being a teaching technique was initiated by Novak, during a particular time that he was doing his research work and wanted to understand the knowledge of children in science at the University of Cornwall (Novak & Canas, 2008). Concept maps are information carrying structures which indicate the root elements of how concepts relate in an organizational chart form with nodes and links arranged in two dimensional spaces. The concepts are represented in labelled boxes.

The notes are connected to each other by links in the form of short phrases or verbs that shows or explains relationships which exist between concepts (Mintzes, Wandersee & Novak, 2005). Concept mapping reduces rote memory and also ensures that learning is meaningful (Novak, 1998). Concept mapping enhances meaningful learning because they make the relationships between concepts very clear for the learner. Even though the technique was originally developed for the purpose of evaluation, it can equally be used in the teaching industry to teach scientific concepts. This technique is currently applied in various areas of the educational sector, including the development of curriculum (Mintzes, Wandersee & Novak, 2005).

This strategy of teaching engages the students more effectively than the traditional or expository texts. Research has shown that teaching students by using the concept mapping strategy enables the learners to easily choose, arrange and remember important ideas that they learn. It also enables learners when it comes to the issue of transferring the learning skills and thinking abilities to real-life circumstances and content.

Problem Statement

The academic performance of students in biology topics such as respiration at the Senior High School level in Ghana continues to decline. According to the West African Examinations Council's Chief Examiners' reports for Senior High School (SHS), students writing the elective examinations struggle with biological concepts related to cellular respiration (WAEC; 2015; 2016, 2017; 2018, 2019, 2020). One major factor that contributes to student performance includes teachers' instructional approaches (Casanoves et al., 2017). The most common instructional strategies used by teachers to deliver concepts in Biology at the senior high level include; conventional method, demonstration, discussion and note-taking (Ayimbila, Pappoe, Yaw, & Azure, 2021). Instructional approaches that demand students' active participation in task accomplishment is absent in the Ghanaian classroom (Azure, 2015). The traditional, teacher-centered, lecture method is still used in teaching biological concepts by majority of the teachers at the second cycle schools in Ghana (Amadu, 2018). This approach to teaching places the focus on the teacher, forces students to adopt a passive role in their own learning (Garret, 2008) and is not particularly as effective, compared to the alternative student-centred approaches, of improving

students' academic performance (Precious, & Feyisetan, 2020). As such, it is better for learners, and improves understanding when they are taught with more student-centered approaches. One of these student centered strategies that is capable of helping students gain conceptual understanding of biological concepts is concept mapping. Concept mapping has been shown to improve students' understanding in both higher order and lower order tests (Bramwell-Lalor & Rainford, 2014). This may perhaps be due to the ability of this technique to help learners make connections between the scientific concepts they are learning. It also helps them organize their thoughts, visualize the connections between important scientific ideas in an orderly way, and reflect on what you have learned and know (Apaw, Owosu, Frimpong & Adjibolosoo, 2021). Based on this, the application of this technique as a lesson delivery technique in helping students improve their understanding, especially in a topic like cellular respiration is still relevant in the Ghanaian context. Against this background, the researchers felt the need to investigate the effect of concept mapping on students' performance on the concept of respiration in biology.

Specific objectives of the study

The specific objectives of the study were to:

1. Determine the effect of concept mapping on SHS two biology students' academic performance in respiration.
2. **Examine the progression of students understanding as they prepare concept maps in the classroom.**

Research questions

Based on the objectives, the following research questions were addressed in the study:

1. What is the effect of concept mapping on students' academic performance?
2. **What is the progression of students understanding as they prepare concept maps in the classroom?**

Review of Related Literature

Constructivism Learning Theory

This study was underpinned by constructivism theory of learning. Constructivism encourages students to take charge of their own learning through methods like experiments and finding solutions to real-world problems, and also helps them to reflect on their actions and discuss how their understanding is evolving (Mensah-Wonkyi & Adu, 2016). It is this nature of constructivism that allows for student centered approaches like concept mapping because it is an active process where learners construct ideas based on their previous knowledge and understanding (Ayimbila & Akantagriwon, 2021). In a constructivism learning environment, the teacher acts as a coach who directs learners to complete a given task. Constructivism learning theory promotes participatory learning in which learners actively participate in the teaching and learning process. The facilitator understands the misconceptions of students and guide the process to address them (Oliver, 2000).

One positive impact of constructivism is that it eliminates the dominance of the teacher and makes learner an active participant in the teaching and learning process, making the instructor a coach who helps students to construct knowledge (Khalid & Azeem, 2012).

Furthermore, this theory supports the idea of conceptualization of knowledge and holds the idea that as learners examine bodies of knowledge based on what they have gone through, they construct or discover their own knowledge. In this way, students construct knowledge as they engage themselves in active learning (Darmofal et al., 2002), reconciling unfamiliar content with knowledge that is already present in their minds and creating deeper understanding. As already stated, the strengths of constructivist learning are realized in methods like concept mapping and make it a very effective way of delivering biological knowledge or content (Schmid & Telaro, 2018).

Concept Mapping Teaching Strategy

Concept maps have been described as a technique for visualizing concepts and schemes (Novak & Canas, 2006). The concept mapping approach enables an individual or group to visually express the thoughts and ideas of a certain piece of content. The representation of concepts can show the relationship that exists between and among scientific concepts (Schwendimann, 2015).

Concept maps may be drawn by hand on a piece of paper/marker board or with the several, now available software applications available that make it simple to create images, graphs, videos and notes (Jena, 2012). Concept maps have been demonstrated as effective means of learning difficult biological concepts (Choudhary & Bano, 2022) with reported gains in problem solving abilities of students (Baig, et al., 2016). Furthermore, there have been reported increase in students' performance in classes that use concept maps against classes do not (Bramwell-Lalor & Rainford, 2014). Students also perceive concept mapping to be helpful in organizing and integrating information (Buntting, et al. 2006). As shown by the literature, there is overwhelming evidence for the efficacy of concept mapping in the biological science classroom. However, there may be challenges to its widespread adoption which include, as highlighted by Kinchin (2001) may be the teaching orientations or beliefs about science teaching held by teachers themselves and by the underlying philosophy of the curriculum that is to be implemented. Nevertheless, concept mapping has tremendous potential in addressing the poor performance of students in biology, with specific emphasis on cellular respiration.

METHODOLOGY

The study adopted a pretest, posttest non-equivalent control group quasi-experimental design. This is because the there was non-random selection of participants into groups. Senior High Schools in Ghana exist as intact classes and hence two classes were used for the study. One class was assigned as experimental group class and the other class control group class.

The design is illustrated in Table 1 below:

Table 1: Illustration of Research Design.

Groups	Pre-test	Treatment	Post-test
Experimental	Q_1	X_1	Q_2
Control	Q3	X_2	Q4

Where, Q_1, Q3 represents pe-test
Q_2, Q_4 represents post-test
X_1 represents intervention (concept mapping method)
X_2 represent intervention (conventional teaching method)

Sample and Sampling Procedure

The population for the study was made up of all form two students offering Biology as one of their elective subjects. The sample for the research comprised of two intact form two Biology classes. The two intact classes were taken from second year biology classes in the school. The class that was chosen first was made the experimental class and thereafter, named as 2A while the class chosen second was made the control class and thereafter, named as 2B. The SHS two biology students were chosen purposely for this research because the topic 'Respiration' is in second year SHS biology teaching syllabus. The experimental class comprised of 50 students, made up of 25 males and 25 females while that of control class had 50 students, comprising 24 males and 26 females.

Data Collection Instruments

The researchers made use of Respiration Performance Test (RPT) which was divided into pretest and posttest items. The Respiration Performance Test (RPT) items were developed by the researchers and used to collect data. In order to make sure that the content as well as the face validities of the test instrument were achieved, the items were subjected to scrutiny by some experienced science teachers for their inputs to be made. The experts' judgment on the content as well as the clarity of language used were made, which ensured validity of the instruments.

With the issue of ensuring internal consistencies of the achievement tests, the researchers sought for the assistance of two raters in rating the pre-test and post-test respectively. Those raters were teachers who had about 8-10 years' experience in teaching biology, as well as being assistant biology examiners of the West African Examination Council (WAEC). The rating scheme and marks awarded was determined by both the researchers and the raters. In measuring the level of agreement between the raters, the Cohen's Kappa Statistic was considered because the raters were two. The test items had inter- rater reliability of Kappa value of (K= 0.90). This indicated a strong level of agreement between the raters.

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The intervention and control

Before the intervention, both groups were given a Respiration Performance Test (RPT) pre-test. Following this, the interventions were implemented. In the quasi-experimental design, the test intervention group's approach aimed to enhance understanding and learning of cellular respiration through the utilization of concept maps as both assessment tools and learning strategies. The intervention group was guided through a multi-step process of concept map creation. The control group was also put through a traditional teacher-centered lecture, with classroom discussions and question and answer sessions.

The Concept Map/Intervention Group

Learners were first introduced to the concept of concept maps and their benefits as learning tools. Learners were then guided to create practice concept maps, linking steps in the preparation of a local, traditional technology to get them to practice linking ideas and steps. In this case, the preparation of a local beer was used. The emphasis at this stage was also to emphasize exploration and self-directed learning.

After this, the class received a comprehensive lecture on cellular respiration, during which key points were outlined. At the end of the lesson, learning resources, textbooks and notes on cellular respiration were provided to learners as they were divided into five small groups of five students each. Within these groups, they collaboratively constructed individual concept maps on cellular respiration.

At the end of the group constructed concept maps, maps were collected and the entire class came together, with minimal teacher intervention, to collaboratively create a composite concept map that integrated insights from their individual groups and research.
The final concept map was also collected and all the concept maps were organized, and analyzed for areas of understanding, gaps and misconceptions.

The Control Group: Traditional Group Work

The control group differed from the intervention group in that they were not taken through concept map development. Like the intervention, learning and understanding of cellular respiration was facilitated at first through a lecture.
After the lecture, there a classroom discussion led by the teacher with the learners to explore and understand cellular respiration topics. Learners were also provided notes and textbooks to review the lesson before the post-test was conducted.

Comparison:

While both groups received instruction on cellular respiration, the intervention group's unique approach involved using concept maps as tools for assessment, guided learning, and self-directed

exploration. The control group, on the other hand, employed a lecture method with classroom discussions as the primary method of learning and understanding cellular respiration.

Data analysis

To answer research question 1, the pre-test, post-test comparison was used. Here the performance of leaners in cellar respiration before the intervention, and after the lesson was assessed. The results of the two groups were analyzed to acertain whether there were any inherent differences in the performance of the two groups. After the interventions, another test was administered to assess the effect of the interventions. The two groups were analyzed at pre-test and post-test, with an unpaired t-test.

Concept maps were also analyzed using thematic analysis to assess the group and class constructed concept maps for understanding, gaps in understanding and misconceptions. The final concept map was also compared to the group constructed maps to note areas of improved understand and persistent misconceptions.

RESULTS

Research question 1: What is the effect of concept mapping on students' academic performance?
The study results were discussed on the bases of the null hypothesis formulated.
$H0_1$: There is no statistically significant difference in academic performance in the pre-test mean scores of students taught using concept mapping method and those taught using conventional method

Table 2: Summary of Independent Samples t-test of Pre-test Mean Scores of Students in the Experimental and Control groups

Group	N	Mean	SD	Df	t-value	p-value	Remarks
Experimental	50	42.18	8.62	98	0.18	0.86	Not significant
Control	50	42.50	9.21				

Source: Field Data, 2022. Significance level=0.05, df =degree of freedom

A pre-test was conducted to examine the level of understanding of students on the concept respiration before the treatment. The results of comparison between the two classes using independent t-test are shown in table 2 above. From the results, the control group and the experimental group mean score difference was 0.32. This was tested at a significant level of 0.05 to find out if there was any difference statistically between the classes.

From Table 2, $t = 0.18$ and $p = 0.86$. Since $p>0.05$, there was no statistically significant difference between the mean scores of participants. This implies that both groups of students had the same

level of knowledge and understanding on the concept respiration, prior to the interventions that were given.

$H0_2$: There is no statistically significant difference in academic performance between those who are taught respiration using concept mapping approach and those taught using traditional lecture approach

Table 3: Summary of Independent Samples t-test analysis of Post-test Mean Scores of the experimental and control groups of students

Group	N	Mean	SD	Df	t-value	p-value	Remarks	Cohen's d
Experimental	50	77.18	6.10	98	16.33	0.000	Significant	3.266475
Control	50	58.78	5.12					

Source: Field Data, 2022. Significance level=0.05, df =degree of freedom

From table 3, the post-test mean score of students in the experimental group was 77.18 with a standard deviation of 6.10. The post mean score of students in the control group was also 58.78 with a standard deviation of 5.12. the difference in mean score between participants in the experimental and control groups was 18.40.

From table 3, t-value=16.33 and p-value=0.000. Since the $p<.05$, there was statistically significant difference between the post-test mean scores of participants in favour of the experimental group. This implies that the experimental group performed significantly higher than the control group in the concept respiration. This was attributed to the use of concept mapping strategy with the experimental group of students. Hence, the null hypothesis was rejected at $p<.05$. The effect size was also found to be large, with a value of 3.266475. According to Cohen (2013), effect sizes above 0.8 are considered very large. Therefore, it can be concluded that concept map creation outperformed the lecture method by a large margin.

Research question 2: What is the progression of students understanding as they prepare concept maps in the classroom?

In order to answer this research question learners' concept maps drawn from the ten groups of five were thematically analysed to assess their understanding and gaps at this stage. This was then compared to their understanding

Table 4: Students' knowledge and gaps in cellular respiration.

Themes	Understanding demonstrated	Number of groups demonstrating this understanding	Was this understanding demonstrated in the final concept map?
Glycolysis	Start point of respiration	10	Yes
	Purpose of glycolysis	9	Yes
	Energy output of glycolysis (ATP)	8	Yes
	Energy output of glycolysis (NADH)	0	No
	Location of glycolysis	4	Yes
Pyruvate oxidation	NADH produced by conversion of pyruvate to Acetyl-coa before krebs cycle	0	No
Anaerobic respiration and fermentation	Anaerobic respiration leads to lactic acid fermentation	10	Yes
	Anaerobic respiration leads to alcohol fermentation	0	No
Krebs cycle (citric acid cycle)	Kreb's cycle begins with pyruvate	10	Yes
	The location of kreb's cycle	8	Yes
	Kreb's cycle energy output (ATP)	3	
	Kreb's cycle energy output (ATP & $FADH_2$)	2	
	Kreb's cycle energy output (ATP, $FADH_2$ & NADH)	5	Yes
Electron transport chain (etc)	Electron donors from kreb's cycle go to the electron transport chain ($FADH_2$)	4	Yes
	All electron donors go to the electron transport chain	0	No
	Electron transport chain	4	Yes
	Location of the electron transport chain	4	Yes
Overall energy production	Total amount of ATP from cellular respiration	2	Yes

From Table 4, it can be seen that the initial group drawn concept maps showed that students demonstrated an understanding of the start point of respiration, the purpose of glycolysis, and the fact that anaerobic respiration leads to lactic acid fermentation. In addition, students at this stage showed a good understanding of Kreb's cycle, including the fact that it begins with pyruvate and

the location of the cycle. However, there were some gaps in knowledge, such as the energy output of glycolysis (NADH), NADH produced by conversion of pyruvate to Acetyl-co A, or the oxidation of pyruvate, before Krebs cycle, and the fact that anaerobic respiration can also lead to alcohol fermentation. It is also worth noting that only two groups demonstrated an understanding of the total amount of ATP produced from cellular respiration.

After the entire class came together to draw their concept map it can be seen that some gaps remained while some knowledge was incorporated from other groups. Specifically, the final concept map demonstrated an understanding of the start point of respiration, the purpose of glycolysis, and the fact that anaerobic respiration leads to lactic acid fermentation. The final concept map also demonstrated an understanding of Kreb's cycle, including the fact that it begins with pyruvate and the location of the cycle. This is clear evidence of the class learning from each other to incorporate their understanding into the final map. However, there were still gaps. Specifically, the knowledge that NADH was produced pyruvate oxidation and glycolysis (NADH) was still missing. Additionally, the final map did not demonstrate an understanding that anaerobic respiration can also lead to alcohol fermentation. Since none of the groups addressed these gaps, it is only logical that the final map also be lacking in this regard.
Students' errors were also analysed across the two stages of concept map creation.

Table 5: Students' errors in cellular respiration

THEMES	SPECIFIC ERROR	**Number of groups demonstrating this error**	**Was this understanding persistent in the final concept map?**
Anaerobic Respiration and Krebs Cycle	Kreb's cycle shown to branch into anaerobic and aerobic respiration	10	Yes
Krebs Cycle and Electron Transport Chain	$FADH_2$ written as FADH	7 (remaining 3 groups did not describe FADH or FADH2	Yes
	ATP from Kreb's cycle goes to electron transport chain	4	Yes

From table 5.0 it can also be seen that those students made some errors in their understanding of cellular respiration. Specifically, all ten groups incorrectly believed that Kreb's cycle branches into anaerobic and aerobic respiration. Additionally, 7 of the ten groups wrote FADH instead of $FADH_2$, while 4 groups believed that ATP from Kreb's cycle goes to the electron transport chain.

After the class came together to draw the concept maps, all the errors also remained. The errors at the group stages were transferred to the final concept map that was drawn.
The analysis of the progression of their understand suggests that while there was an improvement in learners understanding as they moved from group drawn concept maps to a final consolidated class drawn concept map, students essentially transferred all knowledge, regardless of whether it was a gap, error or correct knowledge.

DISCUSSION OF FINDINGS

This study was conducted to examine the effect of concept mapping on students' academic performance in the concept of respiration.The finding from the study showed that there was statistically no significant difference between the pre-test mean scores of students in the control and experimental groups. This proved that the students were similar in academic performance in the concept of respiration before the interventions. It is also an indication that the student in both groups were similar in terms of their understanding on the concept respiration before the treatment was administered.

Another finding of the study indicated that there was statistically significant difference between the post-test mean scores of students in the experimental and control groups. This proved that students who were taught using concept mapping performed significantly higher than their cohorts who were also taught using conventional method. This finding is in agreement with other similar studies conducted by other researchers. This finding confirmed the finding of Okoronka (2018) and Woldeamanuel, Abate and Berhane (2020) who revealed that the use of concept mapping approach in lesson delivery improved academic achievement of students better than the use of traditional lecture method. These studies provide clear evidence confirming the potential of concept mapping technique in enhancing learners' academic performance in biological and other science concepts. The finding is also in line with Ayimbila and Akantagriwon (2021) that concept mapping teaching approach is effective in improving the academic performance of students in biological concepts. The finding is in agreement with Onyejekwe, Uchendu and Tochi (2018) that students taught with concept mapping teaching method performed better than those taught with lecture method. However, the finding is in disagreement with Adlaon (2012), who indicated in an investigation that when concept mapping technique was applied in teaching learners the concept of balancing nature at the high school level, the learners did not perform significantly better when compared with the results of the other group who were taught using the lecture approach. Adlaon (2012) explained that factors which might have brought this outcome include learners' trauma in concept mapping procedures, non-learners' participation in concept mapping procedures as well as the instructor alone generating concept maps without learners' participation in the action.

The results also demonstrated the ability of concept maps to serve as a formative tool. In this way, learners' understanding was tracked across two stages of concept map formation; specifically, the concept maps drawn by the groups and the final concept map drawn by the class. Here, it was revealed that learners transferred their knowledge misconceptions to their peers. This is perhaps because students do not always know the difference between correct and incorrect information. In this study, when two or more groups knew of a concept or had a peculiar error, this was transferred to the whole class. Overall, this peer instruction or consensus building had a positive effect as correct ideas were favoured in the final concept maps. This has been noted by Tullis and Goldstone (2020) who reported in a study where students were asked whether they would retain or change their initial answers to challenging questions after they had discussed their findings with their peers. Students in their study were more likely to retain their answers if they were correct than if they were wrong. Any gaps that the whole class had were however unaddressed without the intervention of the teacher.

But herein lies the strength of the concept maps to formatively correct these mistakes. The teacher now is armed with specific knowledge about gaps and misconceptions that can be addressed on later instruction. Choudhary and Bano (2022) suggest that concept maps prevent rote learning and allow for effecting teaching and formative assessment. This strength of concept maps in formative assessment has been applied by Marriott and Torres (2016) who developed a table to formatively, and even summatively assess students' concept maps.

CONCLUSION

The study investigated the effect of concept mapping on students' academic performance in the concept of respiration at Fumbisi Senior High School in the Upper East Region of Ghana. The results of the study showed that concept mapping is an effective instructional technique for teaching the concept respiration and for formatively assessing and tracking learner understanding. Students who underwent concept mapping performed significantly better than their counterparts taught using conventional method.

Significance of the study

This study adds evidence to the ability of concept maps to improve and formatively assess learner understanding. From the findings of this study concept maps can be a possible remedy to the poor performance of SHS students in biology topics like cellular respiration. Concept mapping has the potential to help learners to get proper understanding of the various interrelationships that exist between biological concepts.

Limitations of the study

One limitation of the study is that while two treatments were evaluated, the concept mapping group seemed to have an additional layer of interactivity amongst peers that the lecture method did not

have. It is possible that this feature also further enhanced the performance of the concept map group

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