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Concept mapping and cooperative mastery learning teaching strategies in lower secondary school classes: Effects on learning outcomes in photosynthesis

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ABSTRACT

Although the central role of biology in nation's scientific and technological advancement is unquestionable, the academic achievement of students in the subject has been subpar. To cope with this situation, researchers in science education have continued to look for a successful way to teach and learn biology concepts. The present study, therefore, investigated the comparative effects of concept mapping (CM) and cooperative mastery learning (CML) teaching strategies on students learning outcomes in photosynthesis. A non-equivalent pre-/post- test quasi-experimental research design was adopted. 295 secondary school form two students from four co-educational schools made up the sample of the study. Data were generated through photosynthesis achievement test (PAT). PAT was subjected to reliability analysis using Kuder-Richardson 21 (KR-21) and Cronbach's alpha, which yielded a reliability coefficient of 0.82 and 0.95, respectively. Data were analyzed using mainly descriptive statistics, and inferential statistics of analysis of covariance. The findings revealed that both CM and CML enhanced students' achievement ($F_{[1,294]}$=26.165, $p< 0.05$), and the retention of the concept of photosynthesis ($F_{[1,294]}$=9.042, $p< 0.05$). However, CM was significantly more effective than CML. As a result, the recommendation that came up among others was that science teachers should embrace CM in biology teaching as well as other perceived difficult topics in science subjects. Also considered important was to train science trainee teachers to use CM.

Keywords: academic achievement, concept mapping, cooperative mastery learning, knowledge retention, photosynthesis

INTRODUCTION

Biology is one among the science subjects in which knowledge is essentially needed for a nation's technological advances. Biology is the study of living organisms, their relationship to one another considering the environment in which they are (Ahmed & Lawal, 2020; Joda, 2019; Oluwatoyin & Gabriel, 2018). It is a natural science discipline that studies living things including how they came to be, how they are built, how they operate, what these functions are and how they develop (Njoku & Mgbomo, 2021). Therefore, it assists students in understanding natural and environmental concepts, principles, theories, and laws.

Globally, biology knowledge has played a big role to enrich all forms of life left alone, helping to know more about man and others living organisms on earth (Joda, 2019; Tsevreni, 2021). This is because, the knowledge of biology consists not only of a collection of facts, but also more importantly the way they are associated with and interpreted in general theories applied to human life (Umar, 2011). Besides, biological knowledge is a prerequisite for several fields of study that contributes significantly as far as the development of people and nations that are concerned socially, economically, and technologically. Among these, one can cite agriculture and biotechnology, nursing, medicine, and pharmacy just to but to mention a few (Ahmed & Abimbola, 2011; Joda, 2018).

Despite the many advantages of biology education, various body of empirical studies (Bichi et al., 2019; Bizimana et al., 2022; Joda, 2019) have indicated that students across most of the sub-Saharan Africa have difficulties in learning biology topics and consequently have low achievement and concept retention in the subject. In Rwandan context, the situation is not different as the failure rate in the subject is more alarming compared to chemistry and physics (Bizimana et al., 2022).

Numerous empirical investigations carried out in various contexts and settings have shown that the primary causes of students' low achievement in biology include a lack of a thorough understanding of the topics covered in the subject (Byukusenge et al., 2022; Chukwuemeka & Dorgu, 2019; Cimer, 2012; Etobro & Fabinu, 2017; Ezechi, 2019; Fauzi & Mitalistiani, 2018; Nur & Ozkan, 2017; Ozcan et al., 2014; Skribe-Dimec & Strgar, 2017; Wan Nasriha et al., 2021). In addition, other research findings (Joda, 2019; Manishimwe et al., 2023) revealed that the learning environment, students' misconceptions, lack of teaching resources, students study habit all account for most the students' difficulties in learning abstract biology topics.

Other factors not fixed to biology topics but to science in general include students' negative attitude towards the subject and the predominance of traditional note-taking and teaching methods (Joda, 2019; Manishimwe et al., 2023). Indeed, such learning difficulties undermine students' advanced learning of biology and interconnected concepts (e.g., sustainable development, biochemical cycles, and green pesticides) as well as interest in biology or other science subjects (Byukusenge et al., 2022; Candas & Calik, 2022; Kumandas et al., 2019). This as a consequence, has prevented students from achieving the goals set for science and technology in the 21st century, particularly those attempting to advance human welfare (Sandika et al., 2018).

In biology, students are exposed to significant concepts that enable them to understand a variety of processes taking place in the entire world. Among them is photosynthesis, which concerns plants. It involves combining carbohydrates or sugars with water (H_2O) as well as carbon dioxide (CO_2) and the sunlight energy. As a result, oxygen is produced as a byproduct, which thereafter emitted in the air (Aboho et al., 2013; Johnson, 2016). Therefore, for students to understand various aspects of biological processes, especially the energy flow among living organisms, it is essential to understand and retain the content and knowledge of the concept of photosynthesis. Due to its importance, this concept is included in the science curriculum at all educational levels, from primary school to university (Lian & Peng, 2021; Métioui et al., 2016).

Even though there has been extensive research on the concept of photosynthesis, secondary school students are still having trouble grasping and retaining the content of photosynthesis (Eziyi & Nwanekezi, 2016; Hadiprayitno et al., 2019). Additionally, various studies in different times and contexts (Lian & Peng, 2021; Métioui et al., 2016; Nasution, 2018) revealed that photosynthesis is one of the hardest among the biology topics and students in different educational levels have had many misconceptions and errors in the concept. The authors added that the concept of photosynthesis is most of the times hurriedly taught for the sake of content completion. Therefore, students do not adequately conceptualize the concept.

Some of the reasons that contribute to students' difficulty in understanding biological concepts include the subject that comprises numerous abstract and complex relationships between and among concepts, the curriculum, which is overloaded, and the lack of teachers' pedagogical competence in the teaching and learning process (Ajayi & Angura, 2017; Angura & Abakpa, 2018; Cimer, 2012). Furthermore, the majority of teachers prefer the traditional teacher-centered approach to teaching biology concepts. This approach mainly rewards students for being able to repeat information without understanding the subject, and predictably makes them fail in the face of the complex interactions found in biology (Schmid &Telaro, 2018).

In the teacher-centered method, the teacher does talking and writing on the chalk or white board while the students' role is to listen and copy from the board passively (Sandika et al., 2018). This leads to an overloading of information to students, which in turn ends by lowering students' interest and attitude towards the taught subject, resulting in low achievement (Chidubem & Adewunmi, 2020; Sibomana et al., 2021). Teacher-centered method is built on the behaviorism theory in which teachers are merely the sole source of students' teaching and information (Molande et al., 2017). However, this unidirectional information flow renders students passive and unable to create meaningful knowledge in biology teaching and learning process (Gambari & Yusuf, 2017).

Due to the shortcomings of teacher-centered methods, researchers in science education have continued to look for a successful way to teach and learn biology. As result, they have come up with innovative constructivist-based teaching strategies, which are learner-centered and more result-oriented. They recommend therefore a shift from the use of traditional teacher-centered methods to innovative strategies. Since teachers are not the source of knowledge in the innovative teaching and learning process, innovative teaching strategies are student-centered approaches to learning (Bedemo, 2020). Due to their constructivist nature, they foster cognitive growth and consequently enhance academic achievement (Molande et al., 2017).

Among the benefits of innovative teaching strategies include learners' active participation, positive attitude towards subject learning, interest, self-efficacy, boosted engagement, enjoyment of the classroom learning environment, development of communication and social skills, enhanced teamwork, critical thinking and problem solving, which result in addressing individual learning needs and differences (Kigamba et al., 2020; Markina et al., 2022). Therefore, the learner-centered teaching strategy is pertinent to biology instruction as it allows for the construction of meaningful knowledge and hands-on learning by encouraging students to interact with materials and specimens.

Some of the innovative teaching approaches that have come up after research and have proved successful in learning biology in particular and science, in general, include project methods, problem-based learning (Bedemo, 2020), inquiry methods (Manishimwe et al., 2023), concept mapping (CM) (Abamba & Esiekpe, 2021; Ajayi & Angura, 2017; Huang et al., 2017), cooperative mastery learning (CML) (Nkirote et al., 2021), just but to mention a few.

Novak and his acquaintances discovered a way of teaching strategy referred to as CM in the early 70s at Cornell University to compile and display knowledge (Novak & Canas, 2006). CM is a creative teaching and learning approach that combines semantic comprehension and graphic representational thinking (Mutodi & Chigonga, 2016). In this approach that uses a concept map while teaching, concepts are organized in such a way that reflects the relationship from more inclusive to more specific ones (Novak & Gowin, 1984; Wang et al., 2017).

A concept map is a graphical representation of significant relationships among concepts (Wang et al., 2017). It is a form of graphical organizer, which allows students to perceive relationships between and among concepts through a diagrammatic representation using keywords (Filgona et al., 2016). It is a pedagogical and meta-learning technique for assisting learners to organize information about concepts in a meaningful manner to facilitate meaningful learning (Chang et al., 2017). Therefore, CM may be used to improve students' logical thinking by high-lighting links and assisting students in understanding how many ideas fit together to form a greater whole.

CML, on the other hand, is a teaching approach that involves the joint cooperative and mastery learning strategies (Nkirote et al., 2021). It is a hybrid learning technique that combines mastery and cooperative learnings, thus lending itself as a powerful tool for teaching and learning. Teachers who use CML break up their subject-matter lessons into manageable units with clear objectives. Students then complete each unit in coordinated groups. Students must demonstrate mastery of the unit through evaluation, often 80% or higher (Kulik et al., 1999), before moving on to a new learning topic. Moreover, peer tutoring, monitoring in small group discussions, or supplementary assignments are used as remediation for students who do not demonstrate mastery of the subject content (Aggarwal, 2004).

Together CM and CML are strategies that get the learner involved. They recognize individual differences in learners, hence getting them to actively participate in constructing knowledge themselves (Keter & Ronoth, 2016). However, while CM is a teaching strategy using a graphical representation showing the relationship among the concepts, CML is a form of teaching strategy in which learners are involved in similar activities like in cooperative exercise, where after every unit, the learner is exposed individually to the teacher's formative assessment. Students who do not master the material are required to retake it in small groups with other students who have mastered it (Aggarwal, 2004).

CM and CML were chosen in this study due to their effectiveness in enhancing achievement in science subjects (Ajaja, 2013; Awofala, 2016; Kaur & Singh, 2015). The empirical study findings on these instructional strategies showed that the academic achievement of students taught in CM and CML settings was considerably better compared to the ones instructed using conventional methods and teaching techniques. Besides, they are effective at encouraging active participation, interaction, and relationships among learners by exchanging ideas and consequently making learning science subjects including biology less complex (Damaso & Banda, 2019).

Once more, additional studies claim that these strategies can help students retain material better and utilize it more effectively because they help students store information in long-term memory, which enhances retention (Ajaja, 2013; Kaur & Singh, 2015; Ozgun & Yalcin, 2014). Furthermore, they have been found to be effective in teaching large classes (Panhwar et al., 2017). Specifically, empirical research indicated that CM promotes the growth of creatively infused critical thinking, which leads to more effective learning and greater learning outcomes (Hsu & Chang, 2011). Besides, CM improves the knowledge of science concepts by creating connections from two to more concepts(Jack, 2013). It also supports students' growth in problem-solving abilities and their capacity to respond to inquiries requiring the application and synthesis of concepts and well as knowledge retention (Awofala, 2016; Bizimana et al., 2022; Chang et al., 2017; Olarewaju & Awofala, 2011). Moreover, CM helps students visualize their information by using graphical tools that connect the earlier studied theories with recently learned topics (Lian & Peng, 2021; Sing & Moono, 2015).

Photosynthesis as a concept in senior secondary school biology has posed unique and formidable challenges to the students as explicated by different researchers (Métioui et al., 2016; Nasution, 2018; Orbanić et al., 2016). Consequently, the low academic achievement coupled with misconceptions about photosynthesis has a link to using a traditional teacher-centered instructional approaches that disregards students' already existing knowledge nor individual needs and not giving time for students' actively participation in the teaching and learning process. Poor methods of teaching biology concepts translates to students' poor achievement and inability to retain what is learnt in the classroom. For enhancing students' comprehension and learning outcomes, the constructivist strategy has demonstrated to be one of the most successful.

Given the need to enhance students' learning outcome in biology, particularly in Photosynthesis, the choice of an efficient teaching strategy is crucial. Thus, in the light of the enlisted benefits of using CM and CML, this study aimed at examining which of these teaching strategies would be more useful in enhancing students' academic achievement and knowledge retention in photosynthesis.

Research Questions

The following research questions were considered in this study in order to fulfil its main objective:

1. What is the difference in the mean achievement scores between students taught photosynthesis using CM and those taught using CML?
2. What is the difference in the mean knowledge retention scores between students taught photosynthesis using CM and those taught using CML?

MATERIALS & METHODS

Research Design

A quasi-experimental research design was used with a non-randomized, non-equivalent pre- and post-test. The study favored this design because it was impossible to carry out a true experiment on people (Creswell, 2014). This design facilitated the researchers in using intact classes while implementing the interventions without affecting the smooth running of the school activities. The intact classes enabled the researcher to administer treatment without disrupting the normal classroom organization.to some classes while others acted as comparison groups (Creswell, 2014). Creswell (2014) and Fraenkle and Willen (2012) explained that this type of design is easier to set up than true experiments. Owing to the fact that it was not possible for the

Table 1. Research design layout

Groups	Pre-test	Treatment	Post-test	Delayed test
Concept mapping	Pre-test (pre-PAT)	Concept mapping	Post-test (post-PAT)	Delayed test (post-post-PAT)
Cooperative mastery learning	Pre-test (pre-PAT)	Cooperative mastery learning	Post-test (post-PAT)	Delayed test (post-post-PAT)

researcher to conduct a true experiment, a non-equivalent group design was used (Christensen et al., 2015). The pre-test scores were used as covariates of post-test scores and post-post-test scores.

The sample consisted of 295 students from senior two (SS2) in Nyamagabe District, Rwanda. Moreover, participants were drawn from seven purposively selected from mixed secondary schools. SS2 students were chosen because they are stable and were not just introduced to secondary biology like SS1 students. Likewise, they were not preparing the end of terminal examination as it is the case of their colleagues in senior three. Additionally, they are prepared to respond to any biology activity since they have a number of abilities and competencies from the first year of study that have formed their attitudes towards biology. Moreover, SS2 students according to Omwirhiren and Khalil (2016) are more stable in terms of statistical sampling than SS1 and SS3 students.

The purposively selected boarding and mixed schools were divided into two groups and then randomly assigned two groups (CM and CML groups) using a simple random sampling technique. The learners in these groups were taught the photosynthesis concepts by their teachers who served as research assistants after having been trained separately on the use of CM and CML instructional strategies. **Table 1** illustrates the design of this study.

Research Instrument & Validation

Photosynthesis achievement test (PAT) was an instrument used in this study to measure students' achievement and knowledge retention. Using a specification table, PAT with 60 items were generated. The 60 items were formulated based on the unit of photosynthesis as specified in Rwanda's biology curriculum for SS2 students in the competence-based curriculum (Rwanda Education Board, 2015). The items were drawn using the table of specifications so that each content area received the proper number of items depending on the number of periods utilized to teach it and the behavioral objectives for lesson delivery. According to the Bloom's taxonomy of educational objectives in cognitive domains, 60 test items were categorized into five cognitive domain levels (Bloom, 1976) as revised by Anderson and Krathwohl (2001).

The initial 60 PAT items were then validated by two secondary biology teachers with teaching experience over 10 years and two experts in measurement and evaluation from the University of Rwanda. The experts' comments led to the modification of the test items and 50 out of the original 60 items were retained for trial testing. Each item has one correct option (key) and three distracters. The correct option attracts one mark and the total mark obtainable is 50. Additionally, 50 students (23 females and 27 males) from a school not included in the study but with characteristics similar to those of the sample schools participated in a pilot test of the 50-item PAT. From the students' responses, the test questions with a difficult index of 0.40-0.60 and a discrimination power of higher than 0.40 (Anigbo, 2015; Bichi, 2015) were identified and retained, and there were 40 items in the final version of PAT.

Intervention

This study was carried out over one month and three weeks in the second term of the academic year 2022. The teachers in the chosen schools were contacted through their head teachers after receiving approval to use the schools for the study from the district and school authorities, respectively. Biology teachers who worked as research assistants were trained throughout the first week. Five biology teachers underwent separate training of five days on the use of CM and CML strategies. Each research assistant was given lesson plans for the whole period of the study depending on the study group plus instruction on how to use them while teaching. They also received instruction on how to administer the pre- and post-post-tests.

During the second week, the research assistants assisted in administering PAT as a pretest to the study groups. In addition to the written instructions on PAT papers, student respondents received verbal guidance on how to react to questions. One hour and 30 minutes were allotted for the pre-PAT. Treatment for the study groups took place from the third to the sixth week.

Students were required to answer focus questions about the process of photosynthesis on the first day of the actual treatment, and they were also expected to make a summary of the main ideas covered in each day's lesson. With the assistance of their teachers, 18 concepts were identified, and each student made concept maps. Following that, they were permitted to display their concept maps for debate and revision on the blackboard. After their practices and the teacher's correctional comments, computer-assisted reference maps in print form were made available to them to compare with their maps. **Figure 1** displays an example of a computer-made concept map for reference.

The students in CML group were taught the same content using a mixture of cooperative and mastery learning approaches. The initial learning and practice phase took place in cooperative settings after the mastery level. Students completed the practice questions on their own. Students received a diagnostic test (a formative test) at the conclusion of each learning topic based on the material they had learned, along with remedial feedback.

Students who met the predetermined threshold for mastery (80% accurate answers) were asked to help the underachievers (those who earned less than 80% correct responses). In order to do this, diverse student groups of four to six students were created, each of which contained one or two high, one low, and two average achievers. After the adjustments were made, students took the test once more on a parallel form. The classroom teachers finished the photosynthesis lesson by following the same procedures for each topic.

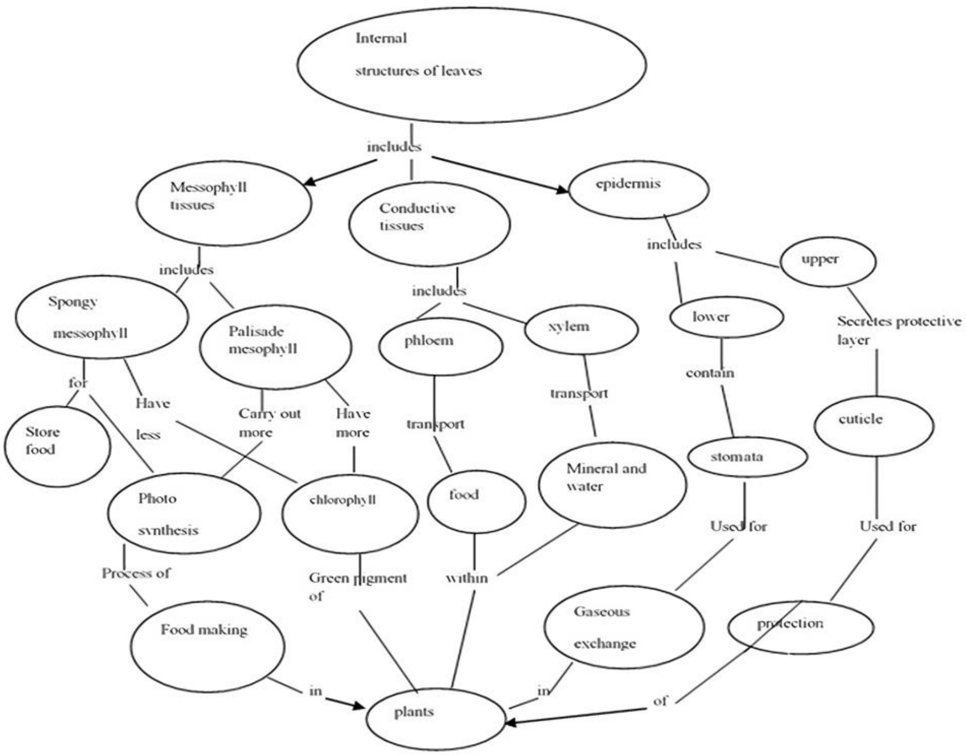

Figure 1. Concept map for internal structure of leaf (Source: Authors' own elaboration)

Table 2. Mean & standard deviation of achievement scores of students taught using CM & CML teaching strategies

Group	n	Pre-test		Post-test		Mean gain
		Mean	Standard deviation	Mean	Standard deviation	
CM	151	30.58	7.23	73.66	9.63	43.08
CML	144	29.84	6.34	63.16	7.03	33.32
Mean difference		0.74		10.16		

PAT was again given as a post-test after the teaching activities in the groups. Research assistants carried out this throughout the seventh week. Group test scripts were gathered and then marked. Three weeks after the post-test, the post-post-test (retention test) was administered to both CM and CML groups as the retention test to measure the level of the students' retention of the material learnt. Following the recommendations of Alebiosu and Micheal (2013), before the retention test administration, the BAT items were reshuffled in order for the students not suspect that a similar tool used as a post-evaluation was repeated as a post-post-test.

Data Analysis Techniques

Data collected through the testing instruments were classified into pre-test and post-test for both study groups. The analysis was carried out using descriptive statistics of the mean and standard deviation to answer all research questions and inferential statistics of analysis of covariance (ANCOVA) to test all hypotheses at 0.05 level of significance. The pretest and post-posttest scores for PAT were subjected to ANCOVA using pretest scores as covariates to the post- test scores. Since the study involved pretesting and post testing, the use of ANCOVA was considered appropriate because it statistically removes the initial difference across the non-randomized groups, the bias that may result from using intact groups whose equivalence was not determined and removes the differences in dependent variables, which may be due to the difference in extraneous variables (Emaikwu, 2012). Therefore, ANOVA was used to take care of the error of the initial difference in the ability levels among research subjects.

RESULTS

Research Question One

In line with the first research question, the pre-test and posttest means, standard deviations for the study groups were computed and compared. The results are presented in **Table 2**.

Table 2 revealed that the overall mean difference between the two groups was 10.16 in favor of CM strategy group. This implies that the students in CM group achieved higher than those in CML group. **Figure 2** illustrates the difference between students taught using CM and those taught using CML in terms of achievement.

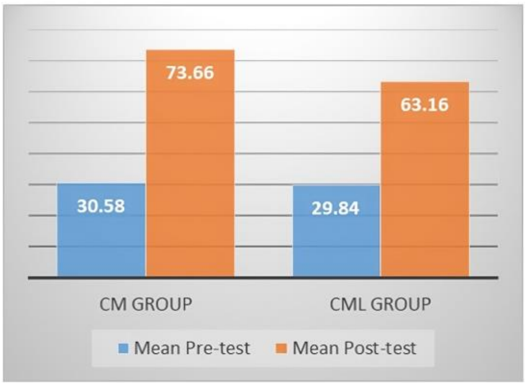

Figure 2. Mean achievement scores for students who were taught using CML & those taught using CML (Source: Authors' own elaboration)

Table 3. ANCOVA of difference in mean achievement scores of students taught photosynthesis using CM & those taught with CML instructional strategies

Source	Type III sum of squares	df	Mean square	F	Significance	Partial eta squared
Corrected model	8,147.293[a]	2	4,073.647	69.155	.000	.321
Intercept	68,552.857	1	68,552.857	1,163.771	.000	.799
Pre-test	82.585	1	82.585	1.402	.237	.005
Groups	8,145.019	1	8,145.019	138.272	.000	.321
Error	17,200.487	292	58.906			
Total	1,425,802.290	295				
Corrected total	2,5347.780	294				

Note. [a]R-squared=.321 (adjusted R-squared=.317)

Table 4. Mean & standard deviation of post-test scores & knowledge retention scores of students taught photosynthesis using CM & those taught with CML

Group	n	Pre-test		Post-test		Mean gain
		Mean	Standard deviation	Mean	Standard deviation	
CM	151	30.58	73.66	9.63	78.75	5.98
CML	144	29.84	63.16	7.03	66.06	8.10
Mean difference		0.74	10.5		12.69	

To determine whether the observed mean achievement score differences among the study groups were statistically significant based on the use of CM and CML in teaching photosynthesis, ANCOVA test at 0.05 level of significance was used. **Table 3** presents the results.

Table 3 shows that there is a significant difference between the mean achievement scores of students taught photosynthesis using CM and those taught using CML in favor of CM instructional strategy ($F_{[1, 294]}$=26.165, $p< 0.05$). Since the associated probability value of 0.000 was less than 0.05 level of significance, the null hypothesis was rejected. Thus, the inference drawn therefore was that CM enhanced students' achievement in photosynthesis better than CML.

Research Question Two

In line with the second research question, the mean knowledge retention, standard deviation scores, and the mean difference between the study groups were computed. The results are presented in **Table 4**.

Table 4 shows that the overall mean difference between CM and CML groups was 12.69 in favor of CM instructional strategy group. This implies that CM instructional strategy group has higher retention capacity than CML strategy group. **Figure 3** illustrates the difference between students taught using CM and those taught using CML in terms of knowledge retention.

However, the descriptive statistics in **Table 4** do not indicate whether the observed mean knowledge retention score differences among the study groups were statistically significant. To determine whether the differences among the study groups were statistically significant, ANCOVA test at 0.05 level of significance was used. **Table 5** presents the results.

Table 5 shows that there is a significant difference between CM instructional strategy (CM) and CML strategy (CML) in favor of CM [$F_{[1, 294]}$=9.042, $p< 0.05$). Since the associated probability value of 0.000 was less than 0.05 level of significance, the null hypothesis was rejected. Thus, the inference drawn therefore was that CM instructional strategy enhanced students' retention in photosynthesis better than CML.

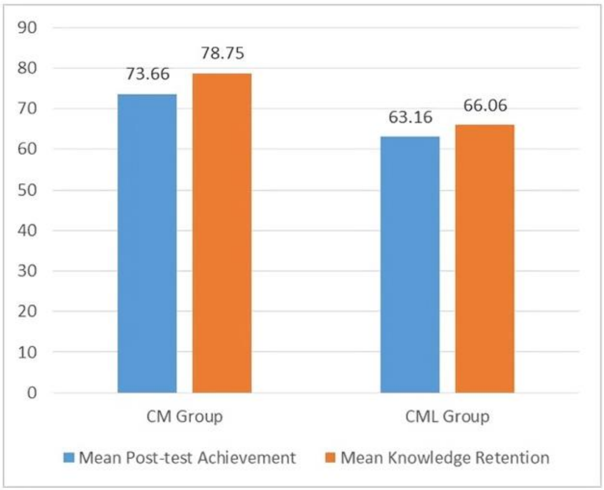

Figure 3. Mean knowledge retention scores for students who were taught using CML & those taught using CML (Source: Authors' own elaboration)

Table 5. ANCOVA of difference in mean retention scores of students taught photosynthesis using CM & those taught with CML instructional strategies

Source	Type III sum of squares	df	Mean square	F	Significance	Partial eta squared
Corrected model	12,011.094[a]	2	6,005.547	120.090	.000	.451
Intercept	77,541.947	1	77,541.947	1,550.569	.000	.842
Pre-test	155.333	1	155.333	3.106	.079	.011
Groups	12,000.414	1	12,000.414	239.967	.000	.451
Error	14,602.538	292	50.009			
Total	1,579,528.250	295				
Corrected total	26,613.632	294				

Note. [a]R-squared=.451 (adjusted R-squared=.448)

DISCUSSION

The findings of this study revealed that both CM and CML enhanced students' achievement in photosynthesis. However, students in CM group achieved higher than those in CML group. This finding is similar to that of Bot and Eze (2016) who found that students taught using CM performed better than those taught using a cooperative learning strategy. Similarly, this finding is in line with the earlier finding of Blessing and Olufunke (2015), which showed that students made to learn using CM strategy were better achievers than their counterparts exposed to the mastery learning approach.

In this study, the presentation of concepts in concept maps shows a clear superiority of CM over CML. According to literature evidence (Romero et al., 2017) verbal and visual communication makes it easy to remember better information. As a result, concept maps as visual learning tools may make difficult and abstract concepts like photosynthesis easier for students to understand. Moreover, Woldeamanuel et al. (2020) explained that the use of concept maps helps learners to organize new information to what they already know. This promotes long-term retention and recalls the information learned. Therefore, the observed difference between CM and CML groups could be the result of CM being more effective than CML in helping students visualizing graphically the relationship between concepts. This visual representation of the concept is missing in CML strategy.

The study findings also showed that students exposed to CM strategy have higher retention capacity than those taught with CML instructional strategy. This finding does not agree with Blessing and Olufunke (2015) whose study found no significant effect of treatment on the retention ability of students taught physics with mastery learning and mind-mapping strategies. Hence, the superiority of CM group over CML group could be as a result of the organization of the concepts in concept map construction. While constructing concept maps, students organized the concepts in a hierarchal manner portraying a meaningful conceptual relationship. This presentation process allows students to retrieve their memory, summarize, and structure their conceptions, thus helping them integrate the concepts learned (Chang et al., 2016).

Apart from that, the concept maps in CM group made students graphically aware of the connections among concepts ranging from the most concrete to the abstract ones. This helped students transform the shapes of contents that were previously in the form of a long description into concise map forms that can aid students in remembering the content more easily. This augurs well with Davies (2011) and Romero et al. (2017) proposal that visual forms are easier for students to understand and retain than written or oral ones. Consequently, the mean retention scores observed difference in biology between CM and CML groups in favor of CM might be due to the result of CM being more effective in enhancing retention of the concept among students than CML does.

Furthermore, based on Paivio's dual-code theory (Paivio, 1991), it is reasonable to predict that employing concept maps improves the processes of content memorization, storage, and recall than in CML. According to Paivio's (1991) dual coding theory, information is encoded in memory both audibly and visually, and if this encoding is done to a subject in both ways, memory processes will increase. Concept maps are visual representations of verbal information that use both ways of encoding (Malekzadeh, 2020). According to Paivio's (1991) idea, using a concept map to learn and recall material is more effective than having the material presented verbally.

CONCLUSIONS

The study intended to determine the effectiveness of CM and CML instructional approaches in improving achievement and knowledge retention in photosynthesis among students. According to the findings, it was shown that both instructional strategies are effective in enhancing the achievement and knowledge retention in photosynthesis. However, where the concept was taught using CM, students performed and remembered the content taught better than those who were taught using CML. The significance of the current study lies in the fact that it increases the number of innovative learner-centered instructional strategies that biology teachers can use to teach and make students learn easily, difficulty, and abstract biology concepts in secondary schools.

Recommendations

As a result, this study provides useful information on how the use of CM and CML could enhance students' achievement and knowledge retention. Therefore, CM and CML should be used by teachers to teach biology, thus enhancing students' achievement and concept retention. Besides, programs of teacher education should focus on reorganizing their special methodology courses to include CM and CML strategies. This would enable prospective biology teachers to receive sufficient CM and CML training. Moreover, curriculum planners should include CM and CML instructional strategies among the appropriate instructional ones as a way to improve teaching biology in Rwandan lower secondary schools.

Limitations

The generalizability of the results of this study, may be constrained given that this study only included students from one district of Rwanda. Therefore, it is advised that additional, comparable studies be conducted to look into the effects of the use of CM and CML in teaching and learning process at the secondary level in different educational settings and contexts in terms of student learning outcomes in science in general and biology in particular.

In addition, this study focused on the concept of photosynthesis. There is a need, therefore, to conduct more studies in other biology-related difficult concepts such as respiration, cell division, and genetics and so on and further confirm the effectiveness of these innovative instructional strategies.

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