International Journal of Evaluation and Research in Education (IJERE)
Vol. 11, No. 2, June 2022, pp. 936~946
ISSN: 2252-8822, DOI: 10.11591/ijere.v11i2.22454

Improving students' cognitive process in biology using concept mapping and cooperative mastery learning strategies

Emmanuel Bizimana[1], Dieudonné Mutangana[2], Adrian Mwesigye[3]
[1]African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), College of Education, University of Rwanda, Kigali, Rwanda
[2]Department of Biology, College of Science and Technology, University of Rwanda, Kigali, Rwanda
[3]Department of Science, Mbarara University of Science and Technology, Mbarara, Uganda

Article Info

Article history:

Received Jun 29, 2021
Revised Mar 24, 2022
Accepted Apr 28, 2022

Keywords:

Biology
Cognitive process
Concept mapping
Cooperative mastery learning
Instructional strategy

ABSTRACT

Students' performance in biology in Rwanda National Examinations has been reported to be unsatisfactory. This demands teachers to shift to methods that enable students to acquire meaningful learning. In an attempt to cope with this situation, the effects of concept mapping (CM) and cooperative mastery learning (CML) on the cognitive process in biology among lower secondary school students in Nyamagabe district, Rwanda was investigated. A quasi-experimental non-equivalent pre-test, post-test control group design was applied to a sample of 449 senior secondary school two (SS2) students (224 males and 225 females) drawn from seven co-educational secondary schools purposively selected from 46 schools. The students were in CM (n=151), CML (n=144) and conventional teaching method (CTM) (n=154) groups. The biology Achievement Test with a reliability of 0.82 obtained from the Kuder Richardson (KR-21) formula was used to collect data. Analysis of Covariance and Bonferroni test were applied for data analysis. Findings revealed that CM and CML groups scored better in all cognitive domains tested than the CTM group. A statistically significant difference between CM and CML was observed in favor of the CM. Based on the findings, it was concluded that the CM and CML are capable of improving secondary school students' mastery of the content taught at all levels of cognition. Therefore, learning with CM and CML could be a viable option for teachers for addressing attainment issues in biology.

Corresponding Author:

Emmanuel Bizimana
African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), College of Education, University of Rwanda
KK 737 St, Kigali, Rwanda
Email: emmanuelbizimana68@gmail.com

1. INTRODUCTION

Biology is one of the science subjects which occupies an important and unique position in the school curriculum. This is because it deals with the study of living organisms and their interaction with non-living organisms [1]. Knowledge in biology is indispensable to both the social and economic development of every individual and nation. This is due to its crucial role as a prerequisite of many important fields of learning that contribute greatly to the technological and economic growth of the nation. These fields include pharmacy, medicine, nursing, agriculture, and biotechnology among the others [2].

Regardless of the great importance of biology, reports and research findings indicate an abysmal performance of lower secondary school students in the subject over the years in most countries in Sub-

Saharan Africa and Rwanda is not exempted. For instance, in Nigeria, the percentage of students that passed biology at credits was very low compared to the total entry [3]. In Ghana, Kenya, Zambia, and Uganda, various reports indicate that the academic performance in secondary school Biology has generally been unsatisfactory for many years [4]–[7]. Likewise, in Rwanda, students are still performing poorly in biology compared to other science subjects [8], [9].

The students' woeful performance is mostly attributed to the lack of deep conceptualization of the topics treated in biology. For instance, studies in different times have constantly revealed that students have difficulty in understanding of key topics like ecology, energy flow in nature, osmosis, photosynthesis, genetics, cell division, protein synthesis, enzymes, nervous system, among others [10]–[12]. The researchers' findings show several reasons presented by students related to students' difficulties in learning these topics. These reasons included: material presented in abstract form [12] using textbooks in teaching and learning process by using examples that are difficult to understand, overload of material charged by the biology curriculum, a classroom environment that does not allow students to enjoy learning biology [13] and teaching methods and strategies that are not related to the content being taught [14].

Moreover, the students' difficulties in understanding biology concepts are mainly caused by ineffective learning as well as poor teaching in the classroom [5], [11]. The authors advanced that teachers do not relate the biology topics to the student's daily activities. In other cases, students are not allowed to actively participate in the teaching and learning process. In this regard, when appropriate teaching and learning approaches are not used in the classroom, students flip to increase some misconceptions about the topics learned especially the ones which are involved with greater complicated and abstract [15].

In the context of Rwanda, it was recently revealed that the teacher-centered teaching approaches, inadequate mastery of subject matter by the science teachers and teaching resources are the current observed as contributing factors that impede effective science teaching and learning and students' conceptual understanding, which in turn contribute to low achievement [16], [17]. The authors explained that most science teachers are reluctant to use activity-oriented methods and rely on inadequate and inappropriate teaching methods such as lecture/exposition methods of instruction for teaching many science concepts. They added that these methods are effective in clarifying text material but quite inappropriate for practical-based science subjects. Moreover, although many Rwandan teachers use learner-centered group work activities, believing that grouping students favors active participation, [17] has shown that this method only engages students in small group work activities, sometimes limited to a question and answer session, which provides no knowledge construction because students are mostly passive throughout the lesson.

In remedying this situation, it is advisable for biology teachers to move away from the conventional mode of knowledge transmission to that of knowledge construction in which students are active participants. This is perceived relevant as the presence of mixed-ability and needs among students. The types of the topics to be taught all require teachers to adapt and develop the corresponding teaching methods [18].

This mode of teaching and learning in which learners construct their knowledge instead of receiving it from teacher is referred to as constructivism [19]. The constructivism focuses on the learner's ability to construct his or her understanding from their prior experiences, thus, make meaning of what they learn. It also emphasizes that the active knowledge construction by learners is socially and culturally rooted [20]. This new trend of teaching and learning has led to the development of innovative constructivist teaching and learning strategies to accelerate students' meaningful learning process. Among these strategies are concept mapping, cooperative and mastery learning [21], [22].

Concept mapping (CM) is an instructional strategy that entails thinking in terms of graphical representation of the relationship among the concepts [23]. This graphic representation is referred to as a concept map. A concept map is usually depicted by circles, forming the nodes of the new word by labelled links [24]. Therefore, a concept map combines visual and linguistic thinking where the text materials are transformed into images. The use of CM in teaching and learning is based on theory of learning which was first put forward in 1968 [25] which emphasized meaningful learning. Ausubel [25] argued that meaningful learning enhances learners' cognitive structure by adding new concepts into the existing conceptual structure. Subsequently, the CM improves meaningful learning as the learners are engaged in a graphical representation of the concepts in hierarchically arranged structures differentiating concepts.

Various advantages of the CM are documented in the literature. For instance, it is an effective teaching strategy due to its big advantage of consolidating and enabling understanding of science concepts as well as making inter-relations between two or more concepts [26], [27]. It also helps students to develop abilities to solve problems and find solutions to questions that require the application and synthesis of concepts [28]. Moreover, the CM improves students' mastery of the content at the higher-order level of cognition [29], [30]. Likewise, CM helps students to actively construct an understanding of concepts thereby making connections between variables of interest in a given subject and supports learners' effort to conceptualize their knowledge into a visually apparent graphical tool that facilitates them to make a connection between the existing concepts with the newly acquired concepts [31]. More so, the use of maps helps in developing long-lasting impressions among students' memory and their retention time hence improving their learning outcomes and facilitates the cognitive representation of a specific topic [32].

Cooperative learning consists of learning by working in groups of students aiming to achieve one mutual goal, using cooperative skills and face-to-face progress feedback [33]. Several studies have acknowledged that cooperative learning improves academic achievement, problem-solving skills, and student-student interaction [34]–[36]. This is due to the fact that cooperative learning gives students opportunities to work together to attain group goals. In this learning setting, it is clear that students discuss the subject matter, help, and encourage each other while learning which lead better group's academic achievement.

Mastery learning is a teaching strategy in which learners are given opportunities to master a particular component of the lesson before continuing to the next [37]. To achieve this, the subject matter is divided into separated parts; each has its predetermined objectives. The teacher assesses the students after each part to determine students who demonstrate the mastery, typically 80%, and those who need more help before moving to new unit material [38]. Students who show mastery of the material are given enrichment tasks, while those who failed to achieve mastery; receive remedial tasks in group discussion. This learning and testing sequence continues until mastery is attained. Thereafter, all students are allowed to move to more advanced content. The principle underlying the mastery learning strategy is that classroom learning is based on time and as the long time is used to learn as the higher rate of learning is increased.

References are made in the literature regarding the benefits of using mastery learning as an instructional strategy [39], [40]. The related findings have proven that the students made to learn through mastery learning in comparison with conventional teaching method (CTM) performed better. Similarly, students in the mastery learning instructional group showed remarkable mean achievement scores in different levels of cognitive domains over their counterparts in the traditional method group [41].

Although cooperative and mastery learning strategies, each has its core characteristics, different empirical researches in different time have evidenced that these instructional strategies can be combined and form cooperative mastery learning (CML) and enhance an effective teaching and learning environment [42], [43]. Besides, once cooperative and mastery learning are combined, they completed each other and yield more positive academic outcomes than individual, and enhances higher-order thinking skills [42], [44]. Accordingly, in CML, students are exposed to the same activity as in mastery learning, but at the end of each unit, each student is provided with feedback from the teachers based on the results from the formative evaluation. Those who fail to achieve mastery are required to relearn the unit content from their peers who attained mastery. For this purpose, students are divided into small equal ability heterogeneous groups. Each group is put under the coaching of their master peers who teach and reteach them till the whole group members demonstrate mastery on the formative test.

Cognitive processes are the process that involves knowledge and how knowledge is used [45]. Cognitive processes include the performance of some cognitive activities such as memorization, producing and understanding language, solving problems, and making a decision [30]. In the 1950s, Benjamin Bloom and his collaborators developed a taxonomy of cognitive objectives, which provides a way to organize thinking skills into knowledge, comprehension, application, analysis, synthesis, and evaluation major levels. Later, Anderson and Krathwohl [46] revisited Bloom's taxonomy and the revised creates an understanding of the learner's behavior and learning outcomes. Six categories are in this new taxonomy. These include remembering understanding, applying, analyzing, evaluating, and creating. The first three categories come under low order thinking process (remembering, understanding and applying) while analyzing, evaluating, and creating come under a higher-order thinking process.

According to Bloom's taxonomy, students easily learn concepts from lower-order to higher-order levels. This implies that to understand higher-level concepts, the lower-order ones must be understood first. Besides, when students are introduced to new concepts, they embark on the cognitive process of integrating these new concepts with their existing ones [30]. Subsequently, the use of the CM helps learners organize knowledge in a comprehensive graphical way and associates prior knowledge with new concepts. On the other hand, the CML ensures that all learners show mastery of the previous concepts to be allowed to move to the next level. The evidence suggests that both the CM and CML can help achieve a higher level of cognitive achievement once they are effectively used. However, there is a need to investigate which strategy between CM and CML can better improve students' cognitive process in biology.

Lower secondary school is a foundation for advanced and professional education. Due to its importance, the subject of biology was made compulsory and examinable at this level. This is because students should have a sound conceptual knowledge of the subject at this level to lay the groundwork for learning the subject at the advanced level. Unfortunately, reports have revealed that lower secondary school leavers do not possess the sufficient basic skills in biology for success in further education. This is evidenced by a big number of students who continue to perform poorly in the subject in lower National examinations.

This failure could be attributed to teachers' use of unsuitable instructional methodologies, especially traditional teacher-centered methods. This is in tandem with previous researchers [47], [48] who noted that most students performed poorly due to the predominant use of teacher-centered instructional strategies. To cope with this situation, teachers must adopt the learner-centered strategies which emphasize contextualized and constructive processes while also equipping students with higher-order thinking skills. Studies have shown that the constructivist instructional strategies are highly successful teaching practices in today's classrooms. This is because as learner-centered approaches, they stress contextualized and constructive processes and equip students with higher-order thinking abilities [49].

According to the literature, CM and CML are among the most widely used constructivist strategies. However, there is a scarcity of research-based information on the combined application of these strategies in one study and on the comparison of their effects on students' cognitive process, each of which has been established to be greater to teacher centered methods. As a result, the study's concern is whether the CM and CML which are more effective than traditional methods but have not yet been applied in biology education in Rwanda would be effective in boosting student cognitive processes in biology. Hence, the purpose of this study was to determine the effects of CM and CML instructional strategies on students' cognitive process in biology among lower secondary school students in Nyamagabe district, Rwanda, with a view of finding out which of the two strategies is more effective.

In the attempt to achieve the purpose, the following null hypotheses were tested: i) There is no significant difference in mean achievement scores in conceptual remembering of students taught biology using CM, CML, and those taught using CTM; ii) There is no significant difference in mean achievement scores in conceptual understanding of students taught biology using CM, CML, and those taught using CTM; iii) There is no significant difference in mean achievement scores in conceptual applying of students taught biology using CM, CML, and those taught using CTM; iv) There is no significant difference in mean achievement scores in higher-order cognitive ability (analysis and synthesis) of students taught biology using CM, CML, and those taught using CTM; v) There is no significant difference in the cognitive process of students taught biology using CM, CML, and those taught using CTM.

2. RESEARCH METHOD

A quantitative approach was used in this study. Besides, a quasi-experimental design, the non-equivalent, pre-test, and post-test with a comparison group was used. This is due to the fact that the participants were not assigned to study groups at random; instead, students' intact classes were employed as the subjects were already assigned to classes to avoid the disruption of normal class settings. Also, the groups were observed and analyzed before and after being exposed to the treatment [50]. The design involves two groups of experimental (CM and CML) and one comparison group CTM. The independent variables in this study were teaching strategies (CM, CML, and CTM), while the dependent variable is the post-test scores of the students in the three groups.

The study took place in coeducational boarding secondary schools targeting all lower secondary school students offering biology subject. Seven schools were purposively selected for the study. The reason for inclusion was equivalence (schools with relatively good standards in terms of infrastructure, teaching resources, and presence of qualified and experienced biology teachers), type of school (Boarding school), school ownership (public and government-aided); gender composition (mixed schools) and student enrolment (senior secondary school two students), and having participated at least once in lower-level National examination. Thirteen intact classes from the selected schools were used in this study. The students in these intact classes constituted the sample size for the study and the sample size was 449 (Male=225. Female=224) students. Five of these intact classes made up of 151 (Male=74, Female=77) students were assigned to the CM group. The next four classes made up of 144 (Male=73, Female=71) students were assigned to the CML group, while the last four classes made up of 154 (Male=78, Female=76) students were assigned to the CTM group. Table 1 shows the design and the samples selected for the study.

Table 1. Research design layout and sample selected for the study

Group	Number of students	Pre-test	Treatment	Post-test
Experimental 1	151	O_1	X_1	O_2
Experimental 2	144	O_1	X_2	O_2
Comparison	154	O_1	X_O	O_2

O_1=Pre-test; X_1=Treatment using CM; X_2=Treatment using CML;
X_O=Treatment using CTM; O_2 =Post-test

The biology achievement test (BAT) was used to measure students’ achievement in biology before and after the treatment. The BAT was developed using a table of the specification to generate 60 items for students’ biology tasks based on the unit of photosynthesis as specified in Rwanda’s biology curriculum for senior secondary school two (SS2) students in competence-based curriculum [2]. The 60 test items were set and categorized into four cognitive domain levels adapted from the Bloom Taxonomy of educational objectives in cognitive domains. A panel of specialists including two secondary school biology teachers with experience over 10 years and two university lecturers established the face and content validity of the BAT. Their comments led to the modification of the test items and 50 out of the original 60 items were retained for trial testing. The 50-item BAT was pilot-tested on 50 students (23 female and 27 male) using a coeducational school that was not part of the study but had comparable characteristics as the sample schools.

From the students' responses, the items showing discrimination power of more than .40 and a difficult index of .40-.60 were retained and the final test comprised 40 items. The Kuder Richardson formula 21 was used to estimate the internal consistency of the instrument and it yielded the reliability coefficient of 0.82. The final BAT is a 40-item multiple-choice objective test with four options (A-D), one correct, and three distracters. The correct option attracted a 2.5 mark giving a total of 100 marks.

This study was carried out over a seven-week periods in the second trimester of the academic year 2020-2021. All classes were given 14 sessions of 45 minutes each. After tendering the introductory letter and gaining permission to use the schools for the study from the district and school authorities respectively, the biology teachers in selected schools were contacted through the headteachers. The first week was used to train biology teachers who served as research assistants. Seven biology teachers were trained separately to facilitate the use of the CM, CML, and CTM in experimental and comparison group respectively. The training mainly focused on the purpose of the study, the topics to be taught, the use and implementation of instructional strategies and methods, and the lesson plans during treatment period, as well as the administration of the pre and post BAT. It was ensured that all research assistants used an equal length of time to facilitate learning of the topics. Depending on the treatment group, the research assistant was given lesson plans for the whole period of the study and instruction on how to use them while teaching. They were also drilled on how to administer the pre-and post-tests. The training lasted for five days.

During the second week, the administration of the BAT as a pre-test in all groups was conducted with the help of the research assistants. Student respondents were given verbal explanations on how to answer questions in addition to the written instructions on the BAT papers. The pre-test was attempted in 1 hour 30 minutes. The third to sixth weeks were for treatment in the experimental and comparison groups. In CM group, three days at the beginning of the third week were allocated to the training of students on the construction of the concept maps using the concepts from the previously taught materials. Students were first given the list of concepts and linking words as well as visual clues on the level of hierarchy. More concept maps were done by students to master the process. For the rest of the treatment period, the concepts in the photosynthesis unit were represented using small boxes with links. Students were assisted to make meaning out of the links in the diagrams that were presented. Besides, students were asked to make many links to the concept being discussed. On the four, fifth and sixth weeks, students constructed concept maps on the process of photosynthesis, the internal structure of the leaf, necessities of photosynthesis, and factors affecting photosynthesis using the concepts identified in class. The unit was complemented by doing practical laboratory and workbook exercises. Their methods and the content derived from the SS2 biology student’s Book and Teacher’s guide [2].

For the CML group, students received initial training on cooperative and mastery learning in three days of the first week. Students were put in small groups of mixed ability and explained how they would work in a team, sharing ideas and working on the given task as a team. Also, the objectives and the expected level of mastery (80%) were discussed. Thereafter, the initial instruction started after which, a formative test was administered to check the attainment of the mastery. Students who did not achieve mastery on the formative task received remedial teaching from their peers who showed mastery. Those who had received remedial tasks were retested with a similar task to check their mastery. After every student had reached mastery, the teacher proceeded to the instruction of the next topic. The same procedures were repeated on all topics taught. To measure the students' attainment, a summative test was administered. The instruction in the CML group which lasted for four weeks was also complemented with the same laboratory and workbook exercises as those in CM group.

In CTM groups, regular class biology teachers covered the same content as in the experimental groups through their regular class teaching methods which normally involved chalk and talk approach, note-taking sessions, group work, and teacher's demonstrations. The unit instruction which lasted for four weeks was also complemented by having students do standard practical laboratory and workbook exercises. After teaching the experimental and comparison groups, the BAT was administered as a post-test. This was done on the seventh week by research assistants. The test scripts in the groups were collected and then marked.

Data were analyzed using mean and standard deviation (SD) and analysis of covariance (ANCOVA) using statistical package for social sciences (SPSS) version 21.0. In the context of ANCOVA, the Bonferroni test was used to make multiple comparison of the group mean scores. The level of statistical significance was set at $p<0.05$.The pre-test scores were used as covariates to adjust for the initial differences between and within the groups [51]. To measure the influence strength of the teaching strategies (i.e., CM, CML, and CTM), the effect size *f* was used [52]. The following Cohen's rough were followed, f=0.1 -small effect size, f=0.25-medium effect size, f=0.4 -a large effect size. Furthermore, before conducting the analysis, data homogeneity was tested using Levene's test.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Pre-test

Before instructional activities, all groups were given the same pre-test to determine their level homogeneity. The pre-test scores were analyzed by Levene's test of determining homogeneity of variance test as shown in Table 2. The table implies that Levene's test of determining homogeneity of variance was not violated. This implies that the students in three groups had equivalent abilities before the commencement of the treatment. As a result, the ANCOVA results can be used to deduce the relationship between the students' tested prior knowledge before treatment, and their learning achievement after treatment.

Table 2. Test of homogeneity of variances

Cognitive domain	Levene statistic	df1	df2	Sig.
Remembering	.300	2	446	.741
Understanding	.105	2	446	.901
Applying	1.900	2	446	.151
Higher order cognitive ability	1.193	2	446	.304
Overall cognitive process	1.256	2	446	.286

3.1.2. Post-test

Following the intervention, all groups were given the identical post-intervention test to see how effective the intervention was. To check whether there was any statistically significant difference in the post-BAT mean scores in cognitive domains among the groups, an ANCOVA test was conducted as presented in Table 3. The table shows that the differences among the mean achievement scores in the post-test among the groups in conceptual remembering were significant ($F_{(2,445)}$=76.08, p=0.000<0.05). With this finding, there is statistically significant difference in conceptual remembering among the groups. Meanwhile, the effect size was 0.255 as indicated by the corresponding partial eta squared is considered a medium effect size. This implies that 25.5% of the variance in the mean achievement scores in conceptual memorization among the groups was explained by the treatment.

Also, the results in Table 3 show a significant difference between the post-test mean achievement scores in conceptual understanding of the groups ($F_{(2,445)}$=37.181, p=0.000<0.05). Thus, there was a significant difference in conceptual understanding between CM, CML, and CTM groups. Meanwhile, the partial eta square indicates a small effect size of 0.143. This implies that 14.3% of the variance in the post-test mean scores in conceptual understanding among the groups was explained by the treatment.

Table 3. Summary of ANCOVA comparing the mean scores of students in the three groups

Source of variation	Cognitive domain	SS	SD	MS	F	Sig.	Partial Eta^2
Covariate	Conceptual remembering	2.849	1	2.849	.091	.763	.000
Treatment		4752.985	2	2376.492	76.082	.000	.255
Error		13899.961	445	31.236			
Covariate	Conceptual understanding	.994	1	.994	.061	.805	.000
Treatment		1207.193	2	603.596	37.181	.000	.143
Error		7224.198	445	16.234			
Covariate	Conceptual applying	3.146	1	3.146	.318	.573	.001
Treatment		304.079	2	152.040	15.357	.000	.065
Error		4405.572	445	9.900			
Covariate	Higher-order cognitive ability	16.850	1	16.850	.698	.404	.002
Treatment		10561.432	2	5280.716	218.86	.000	.496
Error		10736.664	445	24.127			
Covariate	Overall cognitive process	179.069	1	179.069	1.780	.183	.004
Treatment		49399.627	2	24699.814	245.49	.000	.525
Error		44772.285	445	100.612			

Furthermore, results in Table 3 show a statistically significant difference between the post-test mean achievement scores in the conceptual application of the groups ($F_{(2,455)}$=15.357, p=0.000<0.05). Therefore, there was a significant difference in conceptual application between CM, CML, and CTM groups. Besides, the corresponding partial eta squared value indicates an effect size of 0.065, which is considered a small effect size. This implies that only 6.6% of the variance in the mean achievement scores in the conceptual application was explained by the treatment. Hence, the difference in the achievement scores among the groups has a small statistical effect size.

Moreover, the results of the ANCOVA test show a statistically significant difference between the post-test mean achievement scores in a higher level of the cognitive domain of the groups ($F_{(2,445)}$=218.86, p=0.000<0.05). Meanwhile, the corresponding partial eta squared value indicated that the effect size was 0.496. This implies that 49.6% of the difference or variance in the mean achievement scores among the groups has a large statistical effect size. Finally, Table 3 reveals a statistically significant difference between the post-test mean achievement scores in the overall cognitive process of the groups ($F_{(2,455)}$=245.49, p=0.000<0.05). The corresponding partial eta squared value indicated that the effect size was 0.525. This means that the treatment itself accounted for only 52.5% of the overall variance in the students' mean achievement scores in the cognitive process among the groups. This suggests a large statistical effect size for treatment. However, the results of the ANCOVA test alone do not reveal the source of the portrayed significant differences among the groups. Consequently, the Bonferroni post-hoc pairwise multiple tests based on ANCOVA were carried out in Table 4.

Table 4. Bonferroni post hoc comparison for mean achievement scores in the three groups

Cognitive domain	Comparison	Mean difference	Sig.
Remembering	1vs 2	2.67*	0.000
	1vs 3	7.81*	0.000
	2vs 3	5.14*	0.000
Understanding	1vs 2	2.23*	0.000
	1vs 3	3.97*	0.000
	2vs 3	1.75*	0.001
Applying	1vs 2	0.85	0.065
	1vs 3	1.99*	0.000
	2vs 3	1.14*	0.006
Higher-order cognitive ability	1vs 2	4.32*	0.000
	1vs 3	11.67*	0.000
	2vs 3	7.35*	0.000
Overall cognitive process	1vs 2	9.89*	0.000
	1vs 3	25.33*	0.000
	2vs 3	15.35*	0.000

*****p< 0.05 level; 1=CM, 2=CML; 3=CTM

The post-hoc test in Table 4 reveals a significant difference in the post-test mean scores in conceptual remembering between students exposed to the CM and those exposed to the CML in favor of CM. It also shows a significant difference in the post-test mean scores of students exposed to CM and those exposed to CTM in favor of CM. Similarly, a significant difference was also revealed in the post-test mean scores of students exposed to the CML and CTM in favor of CML. Moreover, the table indicates that there was a significant difference in the post-test mean score in conceptual understanding between students engaged in CM and those in CML in favor of CM. There was a significant difference in the post-test mean scores of students exposed to the CM and those exposed to CTM CML and CTM in favor of CML.

Also, the results Table 4 depict that there was no significant difference in the post-test mean scores in conceptual application between students exposed to the CM and those exposed to the CML. However, the mean differences in the post-test mean scores in concept application between students in CM and CTM in favor of CM, CML and CTM in favor of CML. Likewise, the table indicates that there was a significant mean difference in post-test mean scores in higher-order cognitive ability between students in CM and those in CML groups in favor of the CM group. Also, the mean difference in post-test mean scores in higher-order cognitive ability between students in CM and CTM groups was statistically significant in favor of CM, CML and CTM in favor of the CML group.

There was a significant difference in the post-test mean scores in the overall cognitive process between students in CM and CML groups in favor of the CM group. Besides, the mean difference in overall cognitive process between students in CM and CTM and between CML and CTM groups was statistically significant in favor of CM and CML groups respectively. It can be concluded that the students who taught biology using the CM and CML strategies significantly achieved better than those exposed to the CTM in their cognitive domains (remembering, understanding, applying, analyzing, and evaluating).

3.2. Discussion

The study compared the relative effects of CM, CML, and CTM in improving students' cognitive process in biology. The results revealed that there was a significant difference in students' achievement in the investigated dimensions. The Bonferroni test statistical outcome for the achievement scores in the overall cognitive process among the groups revealed that students taught biology using CM achieved significantly higher than their counterparts taught using CTM. This finding is consistent with findings from previous studies [29], [30]. The likely explanation for this finding may be connected to the fact that CM helped students construct, plan and relate independently the concepts learned and constantly link previously learned concepts by revising the maps. This is in line with Chang *et al.* [21] who submitted that concept mapping strategy can facilitate cognitive representation of specific topics, and enhance students' higher-order cognitive abilities. Besides, the use of concept maps enabled the students to break down complex concepts into sub-concepts, which in turn helps them to see the relationships for clarity as well as to combine these sub-concepts using linking words to form a combined meaningful concept. Likely, the finding supports the findings of Chang *et al.* [29] which reported that the students exposed to CM scored better on conceptual memorization, understanding, application, analysis, synthesis, and evaluation than those not exposed to CM.

Also, the Bonferroni test for the mean achievement scores in the overall cognitive process among the groups revealed that students taught biology using CML achieved higher than their counterparts taught using CTM. This finding agrees with Khan and Masood [42] who found that the use of CML enhanced higher-order thinking skills in learning biology. Similarly, the finding buttresses the previous works [41], [42] which found that students exposed to mastery learning strategy showed better achievement in each cognitive domain than those exposed to CTM. The superiority of CML over CTM stems from the fact that in the CML setting, peer and tutoring learning was encouraged, where learners checked each other for mastery. Thus, in this cooperative learning setting, students can gain more from one another than in an individual learning environment.

Besides, mastery learning stressed the need for formative assessment and feedback for each learning unit different remedial materials were prepared. This could explain the result obtained in the CML group. Moreover, CML affords opportunities for accommodating students with diversity in learning abilities among the groups for conversational exchange about the learned concepts. This gives students a chance to talk to each other as well as to stimulate students to be more active contributors. Another explanation is that CML is a hybrid of cooperative learning and mastery learning. This combination of cooperative and mastery learning complements each other. Through its small group settings, cooperative learning provides students the opportunities to communicate and enhance their motivation to learn by fostering active participation [53]. More so, the feedback from students of higher academic ability provides slower learners with ways to analyze their own taught possesses and better reflect on their strengths and weaknesses. Besides, when students explain and clarify concepts to others, they find gaps in their understanding, thus resolved their misunderstanding and fill knowledge gaps [54].

However, the use of cooperative learning only fails to provide a systematic diagnosis of each student's performance and corrective feedback where necessary. Thus, diagnosis of student performance progress and the provision of corrective feedback in mastery learning promote concept development [37]. Consequently, teaching and learning in the combination of cooperative and mastery learning strategies, give room for teachers to diagnose students' knowledge gaps in the content being taught and remediate these deficiencies during instruction. These opportunities are absent in the CTM group where students are at the mercy of the teachers from whom they receive passively knowledge without active participation in knowledge construction [37]. This might be the reason for the outstanding achievement of the CML group compared to the CTM group.

Furthermore, the Bonferroni test for the achievement scores among the groups revealed that the difference in the mean achievement scores in the overall cognitive process between students in the CM and CML groups was statistically significant in favor of students in the CM group. This finding is in line with the earlier finding [38] which revealed that students made to learn using CM strategy achieved better than their counterparts exposed to the mastery learning approach. The likely explanation for this finding may be attributed to the fact that once CM is used in instruction, it helps students develop a cognitive structure that enhances meaningful learning [21]. Besides, in using CM strategy, students comprehended concept meanings, organized concepts in the meaningful relationship between them, and arrived at the coherent and integrated network of the material learned. Moreover, CM combines both visual learning and special representation of information which promote meaningful learning. This visual representation of the concepts is missing in the CML strategy.

4. CONCLUSION

The study concluded that using CM and CML in teaching biology is more beneficial than the CTM in enhancing students' cognitive process in biology. This is due to the fact that these strategies have ability to bring meaningful learning by assisting students to think about, evaluate and analyze biology concepts. Students in CTM groups appeared to be less achievers in the concepts taught. This is because they were not pushed to think deeply as relied solely on their teacher's knowledge. Therefore, for improved students' achievement, the teachers in secondary schools should use these strategies to alleviate the difficulties faced by students in biology.

The findings have crucial educational implications for the teaching and learning of biology in secondary schools in Rwanda. Teaching biology should begin from what learners already know, provide students with corrective and constructive feedback. It needs to ensure all students' proper understanding of the concept taught before proceed to the next level as in the case of CM and CML implementation enhance students' cognitive process. Moreover, some biology topics are difficult for students to comprehend because they are too abstract. Based on the findings of this study, this could be solved by introducing the CM and CML, because they have been demonstrated to be effective in learning biology concepts like Photosynthesis, which is the subject of this study. This study, however, might be reproduced with a longer intervention time and different topic fields. This could help discover the most effective ways to use CM and CML for the benefit of students.

ACKNOWLEDGEMENTS

Our heartfelt gratitude goes to the African center of excellence for innovative teaching and learning Mathematics and Science (ACEITLMS), headteachers, research assistants, and the students in the various schools used in this study. We thank them for their immeasurable support during the course of this study.

REFERENCES

[1] M. A. Ahmed and I. O. Abimbola, "Influence of teaching experience and school location on biology teachers' rating of the difficult levels of nutrition concepts in Ilorin, Nigeria," *JOSTMED*, vol. 7, no. 2, pp. 52–61, 2011, doi: 10.12691/education-7-3-5.
[2] Rwanda. Education Board, *Ordinary level mathematics and science syllabi*. Kigali: Rwanda, 2015.
[3] F. M. Joda and A. A. Mohamed, "Effect of Guided Inquiry teaching method on senior secondary school Biology students Academic Achievement and Retention in Yola Education Zone, Adamawa State, Nigeria," *Multidisciplinary Journal of Science, Technology and Vocational Education*, vol. 5, no. 1, pp. 89–96, 2017.
[4] Y. Ameyaw and M. Okyer, "Concept mapping instruction as an activator of students ' performance in the teaching and learning of excretion," *Annals of Reviews and Research*, vol. 1, no. 4, pp. 93–102, 2018.
[5] C. M. Kambaila and F. K. George Kasali, "Assessing the effects of biology practical activities on academic performance of senior secondary school students," *Journal of Education and Practice*, vol. 10, no. 24, pp. 116–124, May 2019, doi: 10.7176/JEP.
[6] W. Orora, S. W. Wachanga, and F. N. Keraro, "Effects of cooperative concept mapping teaching approach on secondary school students' achievement in biology in Gucha district, Kenya," *Zimbabwe Journal of Educational Research*, vol. 17, no. 1, pp. 1–9, 2005, doi: 10.4314/zjer.v17i1.26052.
[7] P. Ntawiha, "Educational inputs and their implications for output in public secondary schools in Nyarugenge and Nyamasheke districts Rwanda," Dissertation, Kenyatta University, 2016.
[8] Ministry of Education, "2013 Education Statistics," Kigali, Rwanda, 2012.
[9] J. J. Kyado, C. O. Abah, and R. M. A. Samba, "Effect of collaborative concept mapping instructional strategy on secondary students' achievement in difficult biology concepts," *American Journal of Social Sciences and Humanities*, vol. 4, no. 3, pp. 434–447, 2019, doi: 10.20448/801.43.434.447.
[10] G. Hadiprayitno, Muhlis, and Kusmiyati, "Problems in learning biology for senior high schools in Lombok Island," *Journal of Physics: Conference Series*, vol. 1241, no. 1, p. 012054, Jun. 2019, doi: 10.1088/1742-6596/1241/1/012054.
[11] A. B. Etobro and O. E. Fabinu, "Students' perceptions of difficult concepts in biology in senior secondary schools in Lagos state," *Global Journal of Educational Research*, vol. 16, no. 2, p. 139, Nov. 2017, doi: 10.4314/gjedr.v16i2.8.
[12] A. Zeidan, "The relationship between grade 11 palestinian attitudes toward biology and their perceptions of the biology learning environment," *International Journal of Science and Mathematics Education*, vol. 8, no. 5, pp. 783–800, Oct. 2010, doi: 10.1007/s10763-009-9185-8.
[13] A. Çimer, "What makes biology learning difficult and effective: Students views," *Educational Research and Reviews*, vol. 7, no. 3, pp. 61–71, 2012, doi: 10.5897/ERR11.205.
[14] R. W. Gimba, A. M. Hassan, A. A. Yaki, and A. M. Chado, "Teachers' and students' perceptions on the problems of effective teaching and learning of science and technology in junior secondary schools," *Malaysian Online Journal of Educational Sciences*, vol. 6, no. 1, pp. 34–42, 2018.
[15] S. G. Isa, M. A. Mammam, Y. Badar, and T. Bala, "The impact of teaching methods on academic performance of secondary school students in Nigeria," *International Journal of Development Research*, vol. 10, no. 7, pp. 37382–37385, 2020, doi: 10.37118/ijdr.18223.07.2020.
[16] V. Nsengimana, "Implementation of competence-based curriculum in Rwanda: Opportunities and challenges," *Rwandan Journal of Education*, vol. 5, no. 1, pp. 129–137, 2021.
[17] E. Byusa, E. Kampire, and A. R. Mwesigye, "Analysis of teaching techniques and scheme of work in teaching Chemistry in Rwandan Secondary Schools," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 16, no. 6, pp. 1–9, Mar. 2020, doi: 10.29333/ejmste/7833.

[18] P. Kousa, R. Kavonius, and M. Aksela, “Low-achieving students’ attitudes towards learning chemistry and chemistry teaching methods,” *Chemistry Education Research and Practice*, vol. 19, no. 2, pp. 431–441, 2018, doi: 10.1039/C7RP00226B.
[19] C. Epstein, “Constructivism or the eternal return of universals in International Relations. Why returning to language is vital to prolonging the owl’s flight,” *European Journal of International Relations*, vol. 19, no. 3, pp. 499–519, Sep. 2013, doi: 10.1177/1354066113494669.
[20] S. Y. Fernando and F. M. Marikar, “Constructivist teaching/learning theory and participatory teaching methods,” *Journal of Curriculum and Teaching*, vol. 6, no. 1, p. 110, Apr. 2017, doi: 10.5430/jct.v6n1p110.
[21] C.-C. Chang, T.-K. Yeh, and C.-M. Shih, “The effects of integrating computer-based concept mapping for physics learning in junior high school,” *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 12, no. 9, pp. 2531–2542, Jun. 2016, doi: 10.12973/eurasia.2016.1284a.
[22] J. K. Keter and P. K. Ronoh, “Impact of cooperative mastery learning approach on students’ academic achievement in chemistry by gender in Bomet County, Kenya,” *American Journal of Education and Practice*, vol. 1, no. 1, pp. 49–58, Nov. 2016, doi: 10.47672/ajep.92.
[23] P. Mutodi and B. Chigonga, “Concept map as an assessment tool in secondary school mathematics: An analysis of teachers’ perspectives,” *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 12, no. 10, Jul. 2016, doi: 10.12973/eurasia.2016.2301a.
[24] E. Zandvakili, E. Washington, E. Gordon, and C. Wells, “Mastery learning in the classroom: concept maps, critical thinking, collaborative assessment (M3CA) using multiple choice items (MCIs),” *Journal of Education and Learning*, vol. 7, no. 6, p. 45, Sep. 2018, doi: 10.5539/jel.v7n6p45.
[25] D. P. Ausubel, *The psychology of meaningful verbal learning*. New York: Grune and Stratton, 1963.
[26] D. A. Saeed and S. A. Ali, “The effect of using concept mapping strategy on the achievement of eighth-grade school students in biology subject in Erbil City,” *Zanco Journal of Humanity Sciences*, vol. 23, no. 5, pp. 127–147, Oct. 2019, doi: 10.21271/zjhs.23.5.7.
[27] G. U. Jack, “Concept mapping and guided inquiry as effective techniques for teaching difficult concepts in chemistry: Effect on students’ academic achievement,” *Journal of Education and Practice*, vol. 4, no. 5, pp. 9–15, 2013.
[28] A. Olarewaju and A. Awofala, “Effect of concept mapping strategy on students’ achievement in junior secondary school Mathematics,” *International Journal of Mathematics Trends and Technology*, vol. 2, no. 3, pp. 11–16, 2011.
[29] C.-C. Chang, G.-Y. Liu, K.-J. Chen, C.-H. Huang, Y.-M. Lai, and T.-K. Yeh, “The effects of a collaborative computer-based concept mapping strategy on geographic science performance in junior high school students,” *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 13, no. 8, Aug. 2017, doi: 10.12973/eurasia.2017.00981a.
[30] S. Bera and R. Mohalik, “Effectiveness of concept mapping strategy on cognitive process in sciences at secondary level,” *European Academic Research*, vol. 4, no. 4, pp. 3613–3630, 2016.
[31] I. Sen Singh and K. Moono, “The effect of using concept maps as study tools on achievement in chemistry at tertiary level,” *Journal of Education and Practice*, vol. 6, no. 15, pp. 106–116, 2015.
[32] B. E. Ozoji, “Effects of concept mapping technique on Nigerian junior secondary school students’ cognitive development and achievement in basic science and technology (Integrated science),” in *Science Education in the 21st Century*, Singapore: Springer Singapore, 2020, pp. 95–111.
[33] R. E. Slavin, “Cooperative learning in elementary schools,” *Education 3-13*, vol. 43, no. 1, pp. 5–14, Jan. 2015, doi: 10.1080/03004279.2015.963370.
[34] T. D. Bot and J. E. Eze, “Comparative effects of concept mapping and cooperative learning strategies on senior secondary school students’ achievement in Mathematics-Trigonometry in Kano State, Nigeria,” *European Journal of Science and Mathematics Education*, vol. 4, no. 1, pp. 56–66, 2016.
[35] H. Chia-Ling and C. Ya-Fung, “Using large data to analyze the effect of learning attitude for cooperative learning between the high achievement students and the low achievement students,” *Universal Journal of Educational Research*, vol. 5, no. 3, pp. 293–296, Mar. 2017, doi: 10.13189/ujer.2017.050301.
[36] F. Gull and S. Shehzad, “Effects of cooperative learning on students’ academic achievement,” *Journal of Education and Learning (EduLearn)*, vol. 9, no. 3, pp. 246–255, Aug. 2015, doi: 10.11591/edulearn.v9i3.2071.
[37] B. S. Bloom, *Human characteristics and school learning*. New York: McGraw-Hill, 1976.
[38] O. Omolara Blessing, “Comparative effect of mastery learning and mind mapping approaches in improving secondary school students ’ Learning Outcomes in Physics,” *Science Journal of Education*, vol. 3, no. 4, p. 78, 2015, doi: 10.11648/j.sjedu.20150304.12.
[39] G. N. Mitee, Telimoye Leesi Obaitan, “Effect of mastery learning on senior secondary school students’ cognitive learning outcome in quantitative chemistry,” *Journal of Education and Practice*, vol. 6, no. 5, pp. 34–38, 2015.
[40] J. Filgona, J. Filgona, and L. Sababa, “Mastery learning strategy and learning retention: effects on senior secondary school students’ achievement in Physical Geography in Ganye Educational Zone, Nigeria,” *Asian Research Journal of Arts & Social Sciences*, vol. 2, no. 3, pp. 1–14, Jan. 2017, doi: 10.9734/ARJASS/2017/32417.
[41] I. Hussain and Q. Suleman, “Effect of bloom’s mastery learning approach on students’ academic achievement in English at secondary level,” *Journal of Literature, Languages and Linguistics*, vol. 23, pp. 35–43, 2016.
[42] F. M. A. Khan and M. Masood, “The effectiveness of an interactive multimedia courseware with cooperative mastery approach in enhancing higher order thinking skills in learning cellular respiration,” *Procedia - Social and Behavioral Sciences*, vol. 176, pp. 977–984, Feb. 2015, doi: 10.1016/j.sbspro.2015.01.567.
[43] J. K. Keter, “Effects of cooperative mastery learning approach on secondary school students’ motivation and achievement in chemistry in Bomet County, Kenya,” Egerton University, 2013.
[44] F. R. Ghoreishi, M. K. Kargar, B. Ajilchi, and M. Kazemlou, “The effect of combined mastery-cooperative learning on working memory capacity, self-efficacy and academic achievement in grade skipping,” *International Studies in Time Perspective*, Coimbra University Press, 2013.
[45] A. Newen, “What are cognitive processes? An example-based approach,” *Synthese*, vol. 194, no. 11, pp. 4251–4268, Nov. 2017, doi: 10.1007/s11229-015-0812-3.
[46] D. R. Anderson, Lorin W Krathwohl, *A taxonomy for learning, teaching, and assessing: A revision of Bloom’s taxonomy of educational objectives*. New York: Longman, 2001.
[47] O. V. Ajayi and T. M. Angura, “Improving senior secondary students’ retention in electrolysis using collaborative concept mapping instructional strategy (CCMIS),” *Greener Journal of Educational Research*, vol. 7, no. 6, pp. 087–092, Oct. 2017, doi: 10.15580/GJER.2017.6.092417140.

[48] M. T. Angura and V. O. Abakpa, "Impact of cooperative instructional strategies and conventional teaching methods on students achievement and interest in upper basic education science and technology in Nigeria," *International Journal of Innovative Research and Development*, vol. 7, no. 2, pp. 38–45, Feb. 2018, doi: 10.24940/ijird/2018/v7/i2/JAN18085.

[49] M. T. Oluwatoyin, Ariyo Beatrice Gabriel, "Two innovative teaching strategies and academic performance of senior secondary school students in biology: Ekiti state experience," *American Journal of Educational Science*, vol. 4, no. 4, pp. 127-135, 2018.

[50] J. W. Creswell, *Research design: Qualitative, quantitative, and mixed methods approaches*, 4th ed. Lincoln: Sage Publications, Inc, 2014.

[51] N. Gaciu, *Understanding quantitative data in educational research*. London: Sage Publications Ltd, 2020.

[52] J. Cohen, *Statistical power analysis for the behavioral sciences*. Routledge, 2013.

[53] Y. Prihatnawati and M. H. I. A. M. Mohamad Amin, "The effect of module implementation with STAD cooperative learning toward process skills in science and cognitive achievement of 8th grade students," in *International Conference on Learning Innovation*, 2017, pp. 111-115.

[54] N. R. Nnorom and J. C. Uchegbu, "Effect of Mastery learning approach on senior secondary school students achievement in biology in Imo Nnorom," *African Journal of Education, Science and Technology*, vol. 3, no. 3, pp. 100–104, 2017.

BIOGRAPHIES OF AUTHORS

Emmanuel Bizimana is currently a PhD student in Biology Education at African Center of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS) based at the University of Rwanda College of Education (UR-CE). His research focuses on Biology education projects especially innovative teaching strategies and classroom learning environments. He can be contacted at email: emmanuelbizimana68@gmail.com.

Dieudonné Mutangana is a Senior Lecturer at University of Rwanda, College of Science and Technology (CST). He holds a PhD in Biotechnology from Jain University-India Since 2017, he is the Head of Department of Biology. His current research interest in Bioinformatics: Biomolecule sequence analysis, Protein 3D structure prediction, Protein-Protein and, Protein-Ligand interaction prediction, Molecular docking, and Molecular Dynamics Simulation. He is also supporting as Senior Laboratory Analysist-Bioinformatics at National Reference Laboratory, Rwanda Biomedical Centre (RBC). The main responsibilities being for Genomic sequencing for SARS-CoV-2 and Bioinformatics analysis, and the development of both the short and long-term plan for COVID-19 and other pathogens sequencing and Bioinformatics analyses, for a better surveillance of the current and potential future pandemics. He can be contacted at email: mature02@gmail.com

Adrian Mwesigye is an Associated Professor at Mbarara University of Science and Technology (MUST). He received his PhD in Education from Mbarara University of Science and Technology (MUST). He has over 20 years of experience as an Academician with the Mbarara University of Science and Technology (MUST), where he is currently an Associate Professor in the Faculty of Education, department of Educational Foundations and Psychology. His current research interest includes educational administration, especially classroom teaching transformation. He can be contacted at email: arm@must.ac.ug