

Concept Maps as an Effective Formative Assessment Tool in Biology at the Secondary Level

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Abstract

This study is about the effectiveness of concept maps as a formative assessment. It aimed to investigate the effectiveness of concept maps in formative assessment for the teaching and learning of biological concepts at the secondary level. One group pretest-posttest quasi-experimental design was used for this study. The experiment was completed in six weeks. A sample of 46 students was selected from Karimabad District Hunza. Data were collected by conducting a Bioenergetics Diagnostic Test at each interval with and without intervention. It was found that concept maps are useful for the development of a clear understanding of concepts in Biology. Concept maps refrain from rote learning thus promoting critical thinking and reasoning ability and act as an effective classroom instructional and a formative assessment tool. It was concluded that the concept maps can be used as an effective formative assessment tool in Biology at the secondary level.

Keywords: concept maps, formative assessment, science learning

Introduction

Learning and assessment are inseparable because there are two purposes of assessments i.e. ‘assessment for learning’ and ‘assessment of learning.’ However, it has been experienced that most educational systems are designed for the “assessment of learning.” In the course work of teacher education, most of the assessment is done in summative form (Buldu & Buldu, 2010), whereas the grading system of colleges is used for class ranking or comparison among

students. For this purpose, rather than improving their learning, students struggle in different ways so that they might be able to score good grades. One cannot deny the importance of formative assessment (Black & William, 1998), and the role of formative assessment in supporting students learning. Formative assessment has been considered the central part of teaching (Shavelson, 2006). Convincing evidence for assessment is presented by Black et al. (2004) stating that for the improvement of student's learning, assessment acts as a milestone (Buldu & Buldu, 2010). As cited by Jhonson and Jenkin (2009), formative assessment is a kind of assessment that is operational during classroom instruction with the purpose to improve learning by identifying students' needs (Black & William, 1998). Madison-Haris et al. (2012) and Gallagher and Worth (2008) stated that formative assessment is helpful for the teachers for the focused instruction and to achieve learning goals. It also provides support to the learning of students and their learning achievements. Various formative assessment tools are in use in classrooms. Concept mapping is being considered one of the more effective formative assessment tools.

Background

Learning science is different from learning other subjects because students have to construct their knowledge through a meaningful learning process (Ghorai & Guha, 2018). Therefore, various learning patterns are in use in teaching and learning. One of these patterns is the spatial pattern, and concept maps are the best way to assess spatial patterns and encourage meaningful learning (Mintzes et al. 2001; Novak & Gowin, 1984). Teachers utilize various techniques of instruction in the classroom along with different assessment strategies. These instruction and assessment strategies greatly help students to develop meanings of their learning by connecting previously learned knowledge with the new knowledge. In this regard, concept maps help identify different types of concepts, making interlinked connections among the concepts and sequencing these concepts, before the teaching of more precise and accurate concepts (Novak & Canas, 2008). Thus, concept maps help both instructors and learners identify misleading ideas. Hartmeyer et al. (2017) found from the systematic review that “low-directed mapping seems most suitable for formative assessment”(p.598).

Sharma et al., (2013) found that when teaching is supplemented with concept maps, it can be made more interesting and meaningful. Therefore, it is suggested that in teacher education programs, concept maps should be introduced so that the professional development of teachers may be improved.

To help students develop a clear understanding and deep knowledge of any concept, there should be timely monitoring of learning. “Unfortunately in Pakistan, most of the schools, private or government, rank the students as pass or fail based on marks obtained in the final or annual examination only” (Mohammad et al 2018, p.18). Because of this reason, students do not develop conceptual understanding and hence fail to achieve their goal(s). The assessment conducted only at the end of academic sessions is known as a summative assessment, which is not very effective for the learning of learners particularly. As has been identified by Aly (2007), in Pakistan, classroom assessment is not being used as a tool for learning, but it is used at the end of the academic session as a tool to make judgments about the value and quality of schools, teachers as well as students. In addition, examinations are considered the only means of assessment when conducted at the end of a term or a year. For educators and educationists, the main reasons for such assessment procedures are short working days with a heavy burden of the syllabus to be completed in a limited period (Black & Wiliam, 2018; Khattak 2012). Therefore, the teachers must be focused on the completion of the syllabus largely ignoring developing activities for assessment of learning.

Statement of problem

Educational research findings suggest that the choice of learning strategy chosen by the instructor matters a lot to comprehend scientific concepts, promote problem-solving, and develop critical thinking ability among the learners. Active involvement and engagement of the learner in the process of learning by the instructor during classroom instruction facilitate active learning (Munna & Kalam 2021). Although, many school teachers are in the favor of the traditional method for teaching biology concepts, where students are rewarded for their ability to imitate facts without true comprehension. Resultantly, students get failed when they face complex problems in Biology (Schmid & Telaro, 2018). Due to all these issues, the researchers aimed to find the effectiveness of concept maps as an effective formative assessment tool in Biology at the secondary level.

Research Question

What is the effect of concept maps when used as formative assessment in biology?

Research Hypothesis

There will be a significant difference in the academic performance of students when taught through concept maps.

Literature Review

The foremost objective of the current study was to explore the effectiveness of concept maps as it has been considered the best tool for the ‘assessment for learning’ (Bennet, 2011). Woldeamanuel et al.(2020) quoted Irez and Han (2011), that “there is a paradigm shift from behaviorism to constructivism that enhances conceptual learning and the development of attitude towards science”(p.7). Constructivists instruct the educators to utilize concept maps for meaningful learning and refrain from rote learning (Mintzes et al. 2000; Novak & Canas, 2006; Novak & Govin, 1984). Novak and Gowin (1984) were the pioneers to develop concept maps to analyze students’ understanding of the domain of biology. They developed concept maps and used them as teaching and learning strategies based on the work of David Ausubel (1966, 2000). Concept maps are becoming an increasingly important technique to analyze students’ understanding in many disciplines (Budd, 2004; Chiou, 2008; Freeman & Jessup, 2004) particularly in science education (Galvin et al. 2015). Over time, concept maps have been used in multiple ways, one of which is to make learning meaningful which will help the learner to retain knowledge for a longer period (Nicoara et al. 2020).

To assist students’ learning by clarifying their understanding of a concept and building clear linkages between concepts, the use of concept maps has been identified as a powerful instructional tool (Marutirao & Patankar 2016). To find out what has been learned by the students i.e. their prior knowledge and to identify the gaps in the learning process, concept maps have been very useful (Rebich & Gautier, 2005). On the other hand, concept maps, constructed by learners, provide the teacher an insight into the learners’ knowledge and how they organize and represent what they have learned. Based on this information, further, learning can be made successful by using various strategies (Hay et al. 2008). Kamble and Tembe (2013) stated that the performance of students can be significantly enhanced with the utilization of concept mapping strategy in problem-solving as compared to the traditional method of teaching. In different disciplines, concept maps have also been used frequently as an instructional tool (Buldu & Buldu, 2010).

Concept maps have also been utilized to monitor the structural change in the science classroom (Cook, 2017). In biological sciences, concept maps have been used to develop conceptual understanding and meaningful learning (Mintzes et al. 2001). While developing concept maps, students have to think critically to integrate the prior knowledge with the newly learned knowledge. Thus, the learner has to develop the relationships between the concepts which facilitate critical thinking ability in them (Jacobs-Lawson & Hershey, 2002). Concept mapping has been identified as an effective method that promotes critical thinking in students (Kaddoura et al. 2016; Latif et al. 2016). Concept maps can be used by teachers to measure the prior knowledge of students and to encourage them to meaningful learning to enhance achievement (Pangestuti & Zubaidah, 2017). Teachers can develop learning activities using concept maps (Llewellyn, 2013) cited by Mutodi and Chigonga(2016).

It is often observed that many learners are engaged to improve their learning by adding new knowledge to the preexisting one either by conscious or subconscious effort and keep on integrating these new ideas with the existing knowledge. This complexity of knowledge structure can be represented by a unique graphical way i.e. concept map which acts as a valuable tool for this purpose (Vanides et al. 2005).

Concept maps are also being used to assess students learning (Reiska & Soika, 2015). Several research studies have been conducted (Jacobs-Lawson & Hershey, 2002; McClure et al. 1999; Ruiz-Primo et al. 1998; Walker & King, 2003; Williams, 2004) on the use of concept maps as an assessment technique. As cited by Mutodi and Chigonga (2016), various new methods of assessment including concept maps have been dominated by traditional written tests (Dogan, 2011). Supporting Dogan (2011), Detweiler (2012), posits that rather than focusing on conceptual understanding of learners, traditional tests have been utilized for grades only. Several research studies have been conducted (Jacobs-Lawson & Hershey, 2002; McClure et al. 1999; Ruiz-Primo et al. 1998; Walker & King, 2003; Williams, 2004) on the use of concept maps as an assessment technique. Ghani, et al. (2017) and Hartmeyer et al. (2017) found that the construction of concept maps develops students' creative and critical thinking and is useful for formative assessment. Elliott et al. (2008) identified that by including alternative assessment methods to broaden the spectrum of assessments, concept maps allow the learners to build conceptual connections and to reflect on understanding (cited by Mutodi &

Chigonga, 2016). Thus, a concept map helps to expose conceptual understanding of learners that are generally not identified by any other assessment tools that are used commonly such as written tests (Varghese, 2009 as cited by Mutodi & Chigonga, 2016). When students develop concept maps, they connect new information with prior knowledge so that new information is lodged by this activity and helps in developing conceptual understanding (Watson et al. 2016). This method to represent ideas is used to show a relationship between and among concepts and identify the way different concepts relate to each other (Schwendimann, 2015)

Conducting a formative assessment in the classroom, helps the teachers to know how effectively their teaching strategies have worked to develop clear understanding among learners. To ensure improved performance, teachers have to identify the weakness and gaps in the process of learning. This guides the teachers to opt for other strategies so that learning objectives will be attained (Dolin et al. 2018).

In science education, concept maps are frequently utilized as a metacognitive tool (Amin & Hina 2018; Iuli & Helldén, 2004) so that a focused structure of the topic can be provided to the students for the meaningful learning (Iuli & Hellden, 2004). Concept maps provide a better idea to present learning materials in sequential form (Galvin et al., 2015). According to Bennet (2011) in science education, conducting a formative assessment successfully is very much challenging. Formative assessment has been defined as “activities undertaken by teachers and by their students in assessing themselves that provide information to be used as feedback to modify teaching and learning activities” (Black & Wiliam, 1998, online 2010, p.82). With the information of the results of formative assessment, students and the teacher can find whether learning goals are achieved or not. Considering this information, measures can be taken to guide the performance of the learner (Black & Wiliam, 2010). Formative assessment helps the teachers in identifying and responding to the learning of students.

Over time, digital tools have acquired the place of many physical objects. Pailai et al. (2017) have described that the “Kit-Build concept map is a digital tool for creating the learning environment to improve learning achievements, especially the formative assessment in lecture class in elementary school. The evidence-based feedback of an instructor is a key of formative assessment to improve learning

achievements in the classroom situations” (p. 21).

Concept maps have been used in different disciplines such as in physics teaching (Karakuyu 2010; Kokkonen, 2017; Martinez et al. 2012; Mistades, 2009; Senthilkumar, 2017; Sukendar & Setiawan 2018), in ecology and environmental education (Andrews et al. 2008; Kyado, 2019), in Chemistry (Ismono et al. 2018; Kilic & Aziz 2013), in Biology (Kyado, 2019; Udeani and Okafor, 2012), and Biochemistry (Baig et al. 2016). Stoddart et al. (2000) have described the usage of concept maps in other disciplines too such as history (Nair and Narayanasamy, 2017; Salleh & Ismail, 2013), and astronomy (Gulyaev, 2002), and many other disciplines.

Methodology

Research Designs

For this study, one group, the pre-experimental design was employed to investigate the effect of concept maps as an effective formative assessment tool in biology at the secondary level in Hunza. In a pre-experimental design, a one-group pretest-posttest design was used in this study.

The design is explained below:

O X O

Here O is the pretest and post-test before and after the intervention.

Study Treatment Procedure

This study was conducted for 6 weeks during which three units were taught. Students were briefed about the essentials of concept maps and their construction. The researcher asked students to construct their concept maps on the topic taught during the class and they were given the task to share their work with others and present it later in the class.

A similar practice was also continued by the researcher. Sometimes students were asked to develop concept maps individually and sometimes in a group. Pretest of each unit was taken before teaching them with concept maps. To test students’

understanding, a post-test was conducted after two weeks (i.e after completing each unit).

Research Instrument

To conduct the research, three units were taught to the students. To find the effects of intervention i.e. using concept maps, pretest and posttest were administered before and after teaching each unit. Items for the tests were based on constructed response items and multiple-choice items (MCQs). The multiple-choice questions consisted of a stem provided with four choices comprising one correct answer and three distracters. Constructed response question was designed with an illustration and asked to respond to a given question.

Selection of Sample

For this study, non-randomized convenient sampling was used. 46 students of grade IX at the secondary school in Hunza were considered the ample of the study.

Analysis of Data

Tests were conducted before and after the use of concept maps as a formative assessment tool. Scores on pretest and posttest in addition to mean and standard deviation was used to find out the effects of using concept maps as a formative assessment tool. Table 1 and Table 2 compare the summary of arithmetic mean for the results of using concept maps as a formative assessment tool.

Table 1

Mean for Pretest Scores (Pre-intervention)

Test No.	N	Minimum	Maximum	Mean	Std. Deviation
PreTestUnit1	45	4.00	10.00	7.0667	1.42063
PreTestUnit3	45	0.00	8.00	4.8444	1.95350
PreTestUnit5	45	0.00	10.00	6.6444	2.00177
Valid N (listwise)	45				

Table 1 is about the mean of each pretest without an intervention unit. It shows that the mean value for Unit-1 (M= 7.0667) was greater than the mean value obtained in the pretest from Unit-3 (M= 4.8444) and Unit-5 (M= 6.6444) before

using concept maps as a formative assessment tool.

Table 2

Mean for Post Test Scores (with intervention)

Test No.	N	Minimum	Maximum	Mean	Std. Deviation
Posttest Unit 1	45	6.00	10.00	8.3333	1.14812
Posttest Unit 3	45	3.00	10.00	6.6222	1.70945
Post Test Unit 5	45	10.00	10.00	7.6667	1.56670
Valid N (listwise)	45				

Table 2 is about the mean of each posttest without an intervention unit. It shows that the mean value for Unit-1 (M= 8.333) was much greater than the mean value of scores post-test in Unit-3 (M= 6.6222) and Unit-5 (M= 7.667) after using concept maps as a formative assessment tool.

Table 3 given below shows the inferential statistics for scores obtained in pre and post-test for Unit-1 with intervention and others without the intervention.

Table 3

Paired t-test for Unit 1 With Intervention and Without Intervention

Mean	Std. Deviation	Std. Error Mean	% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
			Lower	Upper			
-1.266	1.3038	.19437	-1.6588	-.87495	-6.517	44	0.000

Table 3 indicates the t-calculated value is -6.517 while the t-tabulated value is 2.021. Since, the value of “t-calculated” is greater than the t”-tabulated value”, it can be stated that the hypothesis is accepted. Therefore, it is concluded that concept maps are an effective formative assessment tool in Biology at the secondary level.

Table 4

Paired T-Test for Unit 3 With Intervention And Without Intervention

Mean	Std. Deviation	Std. Error Mean	% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
			Lower	Upper			
-1.77	2.03256	.19437	-1.6583	-0.8749	-6.517	44	.000

Table 4 shows the scores of students in pretest and post-test i.e with intervention and without intervention. It indicates that the t-value is -6.517 while the t-tabulated value is 2.021. Since the value of “t-calculated” is greater than the t”-tabulated value” then, we accept the hypothesis. So it is concluded that concept maps are an effective formative assessment tool in Biology at the secondary level.

Table 5

Paired T-Test for Unit 5 With Intervention and Without Intervention

Mean	Std. Deviation	Std. Error Mean	% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
			Lower	Upper			
-1.022	1.93636	.28866	-1.6039	-0.4404	-3.541	44	.001

Table 5 shows paired t-test of achievements on Unit-5 with intervention and without intervention. It indicates that the t-value is -3.541 while the t-tabulated value is 2.021. Since the value of “t-calculated” is greater than the t”-tabulated value”, we accept the hypothesis. So, it is concluded that concept maps are an effective formative assessment tool in Biology at the secondary level.

Examples of Concept maps developed by the students.

In the following pictures, a few concept maps have been shown. These concept maps were developed by the students after the intervention. It shows how the students conceptualized the taught content and then they developed their concept maps for a better understanding of biological concepts.

Discussion

In this study, it was found that students became engaged in the learning process and developed their concept maps. Buldu and Buldu (2010) also endorsed it and found concept maps helpful to engage students in developing concept maps individually as well as in groups and provide critical self-reflection in the learning process. It was also very interesting that when the researcher checked the concept maps drawn by students and provided timely feedback to them, their learning was improved. It was also observed that when the group of students was constructing the concept maps, increased interactions were observed among the students, and found it helpful in interchanging ideas resulting in their improved learning.

In this study, concept maps were used as a formative assessment and immediate feedback was provided to eradicate misconceptions. It is also obvious from the literature that formative assessment provides timely feedback to the students for their learning whereas the facilitator helps them to avoid misconceptions. According to Pangestuti and Zubaidah (2017), “student’s misconceptions refer to the condition where students develop a concept which is contradictory to the basic science concept or the concept that has been agreed upon among experts”(p.212). Further added, these misconceptions are detected and corrected by using concept maps. The use of a concept map in assessments helps to identify misconceptions or alternative conceptions (Van Zele et al. 2004). Teacher feedback is a fundamental component of the learning process and can support creating a positive classroom atmosphere in which mistakes are identified and eliminated in time so that learning can be improved (Hattie & Timperley, 2007 cited by McMillan, 2010). Miller, (2002) also concluded that feedback offers information to the teachers regarding children’s performance. Kamble and Tembe (2013), have also stated that with the use of concept maps, students’ academic achievement can be improved.

The authors of this study recommend the use of concept maps as a formative assessment tool and underscore that this is a very important aspect of the instructional process. Studies also support the integration of concept maps in classroom practice to provide helpful information to the instructors for improved learning and teaching (Buldu & Buldu, 2010). Working with students in collaboration for the creation of concept maps improves student learning (Beaudry & Wilson, 2010).

Teaching and learning cannot be separated from assessment. The importance of assessment can be judged by the findings of Reeves (2006) where the author has mentioned assessment as one of eight components for the success of a learning environment. Furthermore, formative assessment is much more important and it impacts students learning. Various techniques are employed to carry out the formative assessment. Among them, concept maps are one of the most effective tools. To find out whether concept maps are effective formative assessment tools or not, this study was conducted at the secondary school level in Biology. The results of the present study showed that students scored higher when concept maps were used as a formative assessment tool in classroom teaching compared to when concept maps were not used and students were taught with the traditional method.

These results revealed that concept maps are very effective for clarifying difficult concepts in Biology. The results showed that when learning difficult topics in Biology, a concept map can be used as an effective formative assessment tool, as it is more effective and help to develop in-depth understanding. The researcher found that while developing a concept map students have to think critically and reason for linking two concepts together. This finding is supported by the research of Ghani, et al. (2017) and Hartmeyer et al. (2017) where researchers found that constructing concept develop students' creative and critical thinking and is useful for formative assessment. Critical thinking and reasoning support prolonged learning. This finding is also supported by the work of other researchers as well one of them is Varghese (2009). These results revealed that concept maps are effective in learning difficult concepts in Biology because through critical thinking and reasoning students represent difficult topics in simple ways. Similar findings were observed by Stanisavljević et al. (2017).

The results of this study also revealed that concept maps are an effective tool for formative assessment in Biology at the secondary level. When concept maps are used before the beginning of a lesson, it provides a snapshot of students' prior knowledge so it helps instructors to plan their lesson accordingly. Participants also enjoyed constructing concept maps and also had good interactions among themselves which were helpful in peer learning. In a way, students developed connections between prior existing knowledge and newly learned one and prevented from developing misconceptions.

In addition to this, the study results revealed that simple basic concepts are learned by learners without any difficulty, but many topics require in-depth conceptual understanding. Simple topics can be learned and memorized by rote learning but the topics which require clear conceptual understanding and are complex in nature, cannot be memorized for a longer period by rote learning. For such a difficult topic, concept maps are proved to be very effective. The researchers also found concept maps an important instructional tool for improving students' learning while using them for assessment purposes. Similar findings were observed by other researchers in various fields including medicine (Daley et al. 2016; Daley et al. 2017), history (Nair & Narayanasamy, 2017), and other subjects.

Conclusion and Recommendations

Based on findings and discussion, it is concluded that concept maps are an effective tool for the formative assessment in Biology teaching at the secondary level. Concept maps provide engagement to the students and help in many ways to improve their learning. These are also helpful to eradicate misconceptions among students. Its use can be a valued addition in the process of teaching and learning science subjects. Concept maps must be used for teaching and learning at various levels and in different disciplines. Recommendations are as under:

1. Concept maps may be used to show the relationships among different concepts.
2. Concept maps may be used as remedial work to reduce misconceptions.
3. Concept maps may be used as a tool for formative assessment to gauge the learning of students.

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