Journal of Education and Practice
ISSN 2222-1735 (Paper) ISSN 2222-288X (Online)
Vol.4, No.5, 2013

Concept Mapping and Guided Inquiry as Effective Techniques for Teaching Difficult Concepts in Chemistry: Effect on Students' Academic Achievement

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Abstract
The persistent poor performance in chemistry in Nigerian school system, especially at the secondary level, has been quite a serious problem. The major purpose of this study determined how the adoption of concept mapping and guided inquiry as instructional strategies can enhance more meaningful understanding of difficult concepts in chemistry and increase students' academic achievement. To guide the study a research question and hypothesis were asked, formulated and tested at; 0.05 level of significance. The design was a non-randomized pre-test, post-test, control group quasi-experimental design using intact classes in 251 Senior Secondary three (SS III) Chemistry students in the three senatorial districts of Taraba state which were randomly assigned, experimental and group through balloting using the replacement and withdrawal technique. Face and content validity of instruments were ascertained using the Pearson's Moment Correlation to obtain a reliability coefficient of 0.79. Analysis of Covariance (ANCOVA) was tested at; 0.05 level of significance, means and standard deviation were used to analyze the data. Also, Multiple Classification Analysis (MCA) using the Sheffe test was computed to indicate the direction of the difference. The result of the analysis showed a significant difference between the performance of students exposed to the two experimental groups (concept mapping and guided-inquiry methods) and the control group (expository method), the result of the Sheffe test was in the favour of concept mapping. It was therefore concluded that concept mapping would be an effective teaching strategy for teaching difficult concepts in chemistry since it improved students' performances/retention in the subject.
Keywords: Difficult concepts, expository method, concept mapping and guided inquiry strategy.

Introduction

One of the most cited problems in implementing science curriculum has been the use of inadequate approach for teaching of difficult concepts. A lot of emphasis has been placed on this by the experimental science curriculum projects at both the international and local level. But despite the amount of efforts and emphasis, science teachers (chemistry inclusive) in Nigerian schools still revert to the use of expository (lecture) or "chalk and talk" method for teaching which had been the traditional approach of instruction rather than interactive and investigative approaches (Ifeakor, 2006). Secondary school and college students' knowledge of science is often characterized by lack of coherence and the majority of students engage in essentially rote learning (BouJaoude and Barakat, 2000, Brandt et al., 2001; Jack, 2005).

Effective delivery of science curriculum is no doubt a sine-qua-non to sustainable technological development. Chemistry is one of the fundamental ingredients of technology. There is the need for proper delivery of chemistry curriculum in Senior Secondary Schools. Research findings have shown that a number of topics in chemistry contain some concepts which pose unique and formidable challenges to the students (Betiku, 2002; Jimoh, 2004 and Jack, 2005). It is clear that when concepts are not meaningfully understood by students, they tend to shy away from questions set on them during Senior Secondary Certificate Examination (SSCE). Invariably, this may lead to poor performance of students in these areas and the overall performance of students in Chemistry at SSCE.

If learning strategies and students' achievement have to improve then students have to be introduced to more effective and appropriate teaching methods. Evidence from research works in Nigeria indicated that very little research efforts had been directed at concept mapping and guided inquiry strategies in teaching chemistry especially difficult concepts. The purpose of the study therefore was to find out if the use of these strategies by teachers in chemistry classrooms would enhance more meaningful understanding of difficult concepts and increase students' performance in chemistry. The statement of the problem therefore is: will the application of concept mapping and guided inquiry strategies in instruction facilitate the learning of difficult concepts and improve students' academic achievement in chemistry?

To guide the study a research question and a hypothesis were asked, formulated and tested at; 0.05 level of significance which is:
Research question: Is there any difference in achievement test scores among students taught difficult topics in Chemistry using concept mapping, guided inquiry and the expository methods?
Hypothesis: There is no significant difference in the mean achievement test scores among students taught difficult topics in chemistry using concept mapping, guided inquiry and the expository methods.

Literature Review

Teaching is effective when the approach used brings about a desirable change in the behaviour of the learner. If learning strategies and students' achievement have to improve, then the students have to be introduced to more, effective, efficient and appropriate teaching approaches. A concept mapping and guided inquiry strategy seems to be an answer to a purposeful and meaningful understanding of difficult concepts in chemistry to enhance students' achievement. This makes it imperative to suggest an approach for teaching of chemistry that aims at enhancing understanding rather than promoting memorizing and juggling of facts. An effective way of dealing with this problem is for the teacher to provide a bridge between the unfamiliar concepts and the knowledge which students already have. This is based on the premise that new concepts do not exist in isolation but depend upon others for meaning. Concept mapping has been adequately advocated in literature as strategies for meaningful learning of abstract concepts and assists learners into learning about conceptual changes (Novak 1990). The use of this tool as technique in teaching abstract concepts in chemistry may be observed as a paradigm shift. One big advantage of using concept maps is that during its formulation process, it consolidates a concrete and precise understanding of the meanings and inter-relations of concepts. Thus, it makes learning an active process, not a passive one. Several studies have found the use of concept mapping very effective in science teaching and learning difficult concepts in the sciences, though very few in chemistry (Okafor & Okeke, 2006; Ezekannagha, 2007; BouJaoude & Attieh, 2008; Fechner & Sumfleth, 2008 and Karakuyu, 2010).).
Concept mapping is an instructional tool that is currently gaining popularity in the field of science education. Concept mapping is a pedagogical/metacognitive tool designed to help students learn how to learn (Novak, 1998). A concept map is a diagram showing the relationships among concepts. It is a graphical tool for organizing and representing knowledge. In fact, these are instruments that help with organizing and structuring knowledge. Conceptual maps are very effective; it lets students represent their understanding of domain knowledge in a well-organized format. In concept mapping, users construct a two-dimensional, Visually-based representation of concepts and their relationships. The concept map representation encodes propositions describing two or more concepts and their relationships, in implied natural language sentences. In educational settings, concept mapping exercises have been used to encourage students to actively construct an understanding of concepts and relationships within domains of interest. It was designed to support the learner's effort by externalizing concepts and propositions known to the student, making them visually apparent to facilitate their connection with newly acquired concepts. Concept maps have been used by teachers to assess students' understanding, by students to compare their knowledge and collaboratively renew their understanding, and by experts as a vehicle for modelling and sharing their knowledge. In other word, Concept maps are graphical tools for organizing and representing knowledge. There are two features of concept maps that are important in the facilitation of creative thinking: the hierarchical structure that is represented in a good map and the ability to search for and characterize new cross-links (Novak and Canas, 2008).
In the field of science education, concept mapping has been introduced to face the problem of linking the often multidimensional nature of the subject. Especially in chemistry students are faced with what has been termed three levels of representation: 1) the macroscopic, 2) the microscopic and 3) the symbolic level (Johnstone, 2000). The underlying chemical concepts can be represented on each level which generally results in students having difficulty transferring the concept from one level to the other due to their learning difficulties in chemistry (Ghassan, 2007). In early chemistry education it is essential to guarantee students' ability to transfer knowledge from the macroscopic level, including concepts from the students' everyday life experiences, to the microscopic level, relating to the underlying concepts of matter like atoms, molecules etc. Students have to acquire the knowledge on the microscopic level in order to explain phenomena on the macroscopic level. Concept maps can be seen as one means to facilitate this transfer by either linking concepts on the macroscopic level with those on the microscopic level or help students link the underlying concepts on the microscopic level only. This process is always regarded as constructivist in that the learner constructs knowledge by linking the relevant concepts. With regard to learning in the field of science education, a result of two key meta-analyses (Horton et al. 1993 and Nesbit & Adesope, 2006) generally shows positive effects of concept mapping on students' achievement levels.
Provision of more effective learning and teaching by scientific research method is main goal of many educational organizations and scientific inquiry is one of those effective and innovative methods advocated for in

science and chemistry in particular (AAAS, 1993; National Research Council [NRC], 2001). Inquiry is a method of forming questions about natural world, finding answers, studying and understanding it thoroughly as scientists do rather than knowing generally through an expert or by other means. It is a widely accepted fact by educators that inquiry is very important to reach new knowledge since requires a high degree of communication among environment, content, materials and learners and teachers. Teaching and learning processes during which learners ask their own questions, plan their own inquiries, analyze and discuss their findings and construct their own understandings proves learning to be more effective and long-lasting. The most important feature of this method is to enable both teachers and learners to be researchers, idea propagators and problem solvers. Furthermore, it has some positive consequences such as making students active, developing their understandings, improving their research skills and understandings of the nature of the science (Metz, 2004; Wallace et al., 2004).

Many educators discuss the nature of the inquiry by making use of mostly two concepts such as open inquiry and guided inquiry (Hassard, 2005). Open inquiry is described as a student-centred approach. Students, in this approach, form their own problems and hypotheses, make plans for a scientific research, carry out these researches in order to test their hypothesis and discuss their findings with other friends (Colburn, 2000). This study on research method concluded that this approach has a positive influence on students' academic success (Blonder et al., 2008). However, it was reported that this approach did not have a significant effect on improving students' academic achievements and developing their scientific process skills (Berg et al., 2003; Khishfe and Abd-El-Khalick, 2002; Klahr and Nigam, 2004; Schneider et al., 2001). Different interpretations attributed to this concept by researchers restrict reform works about scientific inquiry to be understood by the teachers (Wallace and Kang, 2004).

Although science teachers play an important role in the implementation of this inquiry model, teachers' this approach faces many difficulties during implementation. Cheung (2007) listed the obstacles emerged during the implementation of this inquiry method in a study with chemistry teachers as follows: insufficient time, teachers' beliefs, scarcity of effective research materials, pedagogical problems, management problems, crowded classes, security issues, fear of encouraging students to misunderstandings, students' complaints, fear of assessment, scarcity of teaching materials etc. The reason for this is the lack of methodological knowledge as well as scientific content (Shedletzky and Zion, 2005). Teachers, beside academic support, need to be informed about learning and teaching processes through research (Lim, 2004) and the usage of guided inquiry methods (Cheung, 2007) in order to resolve teachers' lack of knowledge according to social constructivist approach of learning. According to Furtak (2006), scientific teaching stands somewhere between the boundaries of the traditional method, in which certain answers known by the teachers are transferred to the students and the open inquiry method, in which students construct their own problems and problem solutions. This version is called guided inquiry method which helps in integrating scientific and constructivist rationales together with the facts, principles and rules. Guided inquiry in chemistry classrooms involve students interaction with concrete materials to gain knowledge about some chemistry concepts with the help of the teacher as a guide to enable the students solve problems themselves since they are actively engaged (Moog and Farrell, 2006). In guided inquiry method, teachers and learners play a crucial role in asking questions, developing answers and structuring of materials and cases. The usage of guided inquiry method is very important in transition from lecturing method to other teaching methods which are less and more clearly structured for alternative solutions.

Guided inquiry activities help students to develop their individual responsibility, cognitive methods, report making, problem solving and understanding skills. According to National Research Council (NRC, 2000), guided inquiry environments can best facilitate focusing on learning the development of certain scientific concepts, but while students in the teachers' guidance focus their attention on to the content , they have less suitable means for discovering scientific thinking processes and gaining experience (Kai and Krajcik, 2006).

Materials and Methods

The design for the study was the quasi-experimental design using pre-test, post-test with six intact classes. The study employed a 3 x2 x 2 x3 factorial design. The design consisted of three instructional groups (Concept Mapping, Guided inquiry and Expository Methods) which formed the independent variables. The population consisted of all the Senior Secondary School class III chemistry students from the three senatorial districts of Taraba State from where a sample of two hundred and fifty one (251) students was drawn. Two chemistry teachers from each school which served as instructors were initially trained and used to present the content materials to the students. At the end of the training, the instructors were given copies of the instructional packages comprising of six week instructional unit, a comprehensive lesson plan to be taught and instructional materials. The intact classes were randomly assigned into experimental and control group through balloting using the replacement and withdrawal technique. Face and content validity of the instrument were ascertained, using the Pearson's Product Moment Correlation to obtain reliability co-efficient of 0.79. All the subjects were Pre-tested before treatment. The material learned by the students from where the achievement tests were drawn, was a six week instructional unit drawn from the concepts considered as difficult. During the treatment period, students in the experimental groups were taught using the concept mapping and guided inquiry methods while the control group was taught using the expository method. The treatment lasted for six weeks. At the end of the treatment, Post achievement test scores of students were collected. Four weeks later, the follow up test scores of students were also collected.

Analysis of covariance (ANCOVA), mean and standard deviation were used to analyze data. Also, Multiple Classification Analysis (MCA) using the Scheffe test was computed to indicate the direction of significance.

Results

Table 1 showed the means and standard deviations for the three types of instructional strategies used in teaching difficult topics in chemistry on students' achievement. Students' taught with concept mapping and guided inquiry methods had mean scores of 62.07 and 56.19 respectively while the expository method which served as the control group had a mean of 36.36.

Table 2 showed that the F calculated value 124.60 was greater than the F critical value 3.04. Since the calculated value was greater than the table value, the null hypothesis was therefore rejected which implied that there was a significant difference in achievement among students taught using concept mapping, guided inquiry and the expository methods.

Table 3 showed the post-hoc analysis using the Scheffe test to indicate the direction of the difference for the three instructional methods on students' achievement in Chemistry. Students taught with concept mapping performed better than those with guided inquiry and expository methods having contributed 62.067 to the noticed difference as against 56.19 and 36.36 respectively. The post hoc analysis to determine the direction of significance at; 0.05 level of significance indicated the following:

i. A significant difference between concept mapping and guided inquiry methods in favour of concept mapping;
ii. A significant difference between guided inquiry and expository methods in favour of guided inquiry method;
iii. A significant difference between concept mapping and expository methods in favour of concept mapping.

This finding indicated that among the experimental groups, concept mapping group was significantly better than the guided inquiry group who were in turn better than the expository group. All experimental groups were found to be significantly better than the control group who used the expository method.

Discussion

The study dealt with the effects of concept mapping and inquiry methods in teaching difficult topics in chemistry on students' academic achievement. The study is quite significant and timely considering the persistent poor performance of students in chemistry in senior secondary school certificate examinations. This poor performance of students has been blamed on inadequate techniques of teaching and lack of understanding difficult concepts by students. This led to the search for alternative methods of teaching which will enhance students' achievement in chemistry. This study is significant in the sense that it has affirmed the relevance of concept mapping and guided inquiry in improving learning when used as an instructional strategy.

One major finding of this study is that students taught using concept mapping scored higher marks in chemistry achievement test than those taught using guided inquiry and expository methods. Result from Table 1 showed that concept mapping had a mean score of 62.07, guided inquiry had 56.19 and expository method had 36.36. This was further confirmed with the ANCOVA result in Table 2 where the f-value was found to be higher than the table value leading to rejection of the hypothesis. The result indicated that the group taught using concept mapping performed significantly better than those taught using guided inquiry and expository methods. This implies that concept mapping was more effective in enhancing and facilitating better understanding of difficult concepts in chemistry. This finding is in agreement with Karakuyu (2010) whose result showed that drawing concept map instruction was more effective than traditional instruction in improving physics achievement of the participating students. With regard to learning in the field of science education, results of two key meta-analyses (Horton et al., 1993; Nesbit & Adesope, 2006) generally showed positive effects of concept mapping on students' achievement levels which also supported this study; however the studies by BouJaoude & Attieh (2008) and Sumfleth (2008) found that the effects of concept mapping in chemistry are generally small.

Conclusion

This study highlighted the effects of concept mapping and guided inquiry approaches in teaching difficult topics in chemistry on students' academic achievement. Result from the findings indicated that the concept mapping method was more effective and superior to the guided inquiry method which also was a better teaching strategy to the expository mode in improving students' achievement in chemistry. It can be concluded that concept mapping and guided inquiry would be suitable methods for teaching difficult concepts in chemistry in secondary schools. This was based on the fact that these methods made the chemistry teachers to adequately plan, prepare for lessons and present lessons that guaranteed active learning as shown from students in the study who did significantly better than those taught with expository method.

The study also concluded that the students that used concept mapping method enhanced better performance in chemistry difficult concepts than either guided inquiry or expository method. This showed that concept mapping seems to be the best alternative to experimental studies since it had the potential for the retention of knowledge for a long time. All the students who used concept mapping performed better since it helped them to determine relationships among concepts, sharpened their understandings and increased their critical thinking.

Recommendations

Based on the findings of the study, the following recommendations were made:

1) Chemistry teachers should resort to using concept mapping as a teaching strategy as an alternative to laboratory experience in situations where laboratory facilities are not available since it guarantee the retention of chemistry knowledge, shows concepts connectivity links and thereby improves students' performance in chemistry.
2) Concept mapping is also recommended to schools in developing nations as a reliable method for study in chemistry since most of their schools lack equipped laboratories and instructional materials for hands-on activities.
3) The Government should utilize the services of various bodies such as Science Teacher Association of Nigeria (STAN), All Nigeria Conference of Principals of Secondary School (ANCOPSS) and National Union of Teachers (NUT) to organize Seminar, workshop, conference and in-service training to inform and train chemistry teachers on the use of innovative teaching method especially concept mapping and guided inquiry since they have proved effective.
4) Curriculum planners, developers and science educators should take cognizance of this method (concept mapping) and guided inquiry which are innovative and effective pedagogical strategies in chemistry classrooms.

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Tables

Table 1: Mean and standard deviation of the students taught using concept mapping, guided inquiry and the expository methods

Treatment Groups	Mean	N	Standard Deviation
Concept mapping	62.07	101	14.60
Guided inquiry	56.19	67	1.116
Expository	36.36	83	4.87

Table 2: ACOVA summary table of difference among students taught using concept mapping, guided inquiry and expository methods

Sources of variation	Sum of squares	Df	Mean square	F Ratio	F Critical	Sig.
Corrected Model	319943.89	3	1064.96	84.11		000
Intercept	16203.37	1	16203.37	127.99		000
Pre-test	226.04	1	226.04	1.79		183
Treatment	31545.82	2	15772.91	124.60	3.04	000
Error	31268.11	247	126.592			
Total	741916.00	251				
Corrected Total	63212.00	250				

Significant: $P \leq 0.05$ F= Critical value=3.04

Table 3: Scheffe test to determine the direction of the difference of instructional methods on students' achievement in Chemistry

N	**Subset for alpha=0.05**			
Treatment Group	**1**	**2**	**3**	**1**
Concept mapping	101			62.0693
Guided inquiry	67		56.1940	
Expository	83	36.3617		
Significant		1.000	1.000	1.000