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Enhancing and Assessing the Conceptual Understanding of Nigerian Senior Secondary School Physics Students in Waves Using Concept Mapping Technique

OkoronkaUgwumba Augustine
Associate Professor, Department of Science Education,
Modibbo Adama University of Technology, Nigeria

Abstract:
The study investigated the use of concept mapping technique for enhancing and assessing conceptual understanding of secondary physics students in waves in Yola metropolis, Adamawa State, Nigeria. Design involved a pretest, posttest control group, quasi-experiment which used both qualitative and quantitative methods to collect and analyze data. A sample of 130 SS2 subjects in intact classes (N=68, experimental group and N=63, control group) from two purposively selected public schools participated in the study. Two major questions guided the study while two valid and reliable instruments namely: Achievement Test in Waves (ATW) and Concept Map Scoring Rubric were used for data collection. The results indicated that concept mapping technique enhanced conceptual understanding of subjects. There was a high positive significant relationship between multiple choice test scores and concept map scores of subjects such that up to 50% prediction of one can be made from the other. Based on the findings, it was concluded that concept mapping has potency to improve achievement and enhance conceptual understanding of the difficult concept of waves in physics when employed both as instructional technique and assessment tool at the secondary school level.

Keywords: *Concept mapping, knowledge construction, achievement, conceptual understanding, knowledge representation, assessment*

1. Introduction

Education is one concept that has defied a universally accepted definition due its nature. Be that as it may, philosophers in the field of education such as Hirst (1974) and Barrow (1976) posit that it has to do with the inculcation of what is of worth. These authors insist that an educated person must possess knowledge and understanding both in depth and breath. In line with these ideals, the initiation of (young) people into different forms of knowledge (e.g. physics) and the development of cognitive understanding constitute the thrust of all educational endeavors. Consequently, the ultimate goal of science teaching at all levels of education is geared towards the enhancement of conceptual understanding, acquisition of scientific attitude and scientific inquiry (Gabel, 2008). This is necessarily so because the scientist is faced with different kinds of problems and situations whose solution call for a 'kind of knowing' that demands and warrants flexible thinking and action. Thus, understanding offers what Halford (1993) calls cognitive autonomy which helps to free its owner from inflexible act, domination and exploitation. Unarguably therefore, understanding is what depicts quality in knowledge because it makes sense of disparate, non-comparable sets of information.

As plausible as these views seem, there are obvious problems associated with teaching for understanding which have made it an unattractive target of instruction and assessment. First, is the specification of the exact meaning of understanding. It can be argued that understanding is a concept that cannot be pinned down to one meaning. It rather possesses different meanings in different contexts. Second, understanding is abstract in nature, neither easy to measure nor transmitted from one person to another. It must be created by the individual who must consciously and willingly make connections through the application of mental effort which only he/she would supply. Newton (2000) reasoning along this path, conceived understanding as an economic way of knowing which captures several particulars about our world and narrows them to a consistent manageable size and order. A direct benefit of this view is that understanding can be inferred as indicator of the quality of learning.

Regrettably however, most educators including those in science have tended to equate achievement with how well students score in exams (Goodlad, 1998). Such exams more often than not require factual information from students' memorized answers. This practically reduces science to rote learning, a boredom and a chore. Besides, it tends to negate the ideal of conceptual understanding in science. The end result of all these is negative attitude, low enrolment and poor achievement in science subjects in general and physics in particular (Okoronka, 2004; Mbamara&Eya, 2015; Kiptum, 2016; Banjong, 2016).

Despite the fore mentioned challenges in science teaching and learning for conceptual understanding, there seems to be light at the end of the tunnel. Firstly, the process of conceptual understanding can be improved by providing the learner with relevant support to enhance its occurrence. Secondly, the learner who is the builder of his/her own knowledge in consonance with the theory of human construction of knowledge (Von Glasser Field, 1995; Novak, 1993; Selvi, 2012) during the process of making connections (which creates meaning and understanding) can be supported in diverse contexts. Furthermore, knowledge and understanding have a representational nature which enables their expression both in spoken and non-spoken (symbolic) forms (Greca& Moreira, 2000). These representational forms can be applied or copied by the teacher to enhance and create understanding during a learning situation. The concept mapping technique can appropriately serve this purpose. Concept mapping is a technique for organizing and representing knowledge in graphical format (Novak & Canas, 2008). Concept mapping helps learners to transform and generate new ideas, discover new concepts and the propositions that connect them, integrate new concepts with older ones and gain enhanced knowledge of a topic and evaluate information (Inspiration Software Inc, 2018)

Concept maps have their theoretical underpinning in the works of David Ausubel. The fundamental idea of Ausubel's (1968) cognitive theory of meaningful learning is that learning occurs through a process he calls 'subsumption'. Here, new knowledge composed of more specific, less inclusive concepts is linked to more general and inclusive concepts and propositions that are already part of a learner's cognitive structure. In 'superordinate' learning, the theory explains that new, more general, inclusive and more powerful concepts are acquired which subsume existing ideas in a learner's framework of knowledge and results into significant re-ordering or cognitive structures able to produce the kind of conceptual change needed during insightful learning.

Ausubel advanced two additional concepts to explain the changes which occur as knowledge is being restructured during meaningful learning as progressive differentiation and integrative reconciliation. By progressive differentiation, Ausubel refers to the gradual elaboration and clarification of concept meaning which occurs during subsumption and superordinate learning. The strongly hierarchical knowledge structures of science learning benefits immensely from progressive concept differentiation as it results in increasing levels of hierarchy or branching off from central concepts. On the other hand, integrative reconciliation as conceived in the Ausubelian theory, is a process occurring during meaningful learning in which there is explicit delineation of similarities and or differences between related concepts. In contrast to meaningful learning, Ausubel equally describes rote learning as involving accumulation of isolated propositions in cognitive structure of the learner instead of the development of strong hierarchical frameworks of successfully more inclusive concepts that are characteristic of meaningful learning.

From the foregoing, it could be noted that the nature and characteristics of concept maps are in total agreement with the Ausubelian theory. First, concepts and propositions are the building blocks of knowledge (Novak &Canas, 2006). Therefore, concept maps serve as good tools to illustrate and represent the hierarchical, conceptual and propositional nature of science knowledge. Also, concept mapping in tandem with Ausubelian ideology of learning, stimulates the process of constructing and integrating new knowledge into existing structures by making explicit the relationships between concepts.

Furthermore, the representational nature of all forms of knowledge (Greca& Moreira, 2000) makes concept maps a veritable tool for communicating, negotiating, understanding, reasoning and problem solving. Knowledge representation could be done in spoken or non-spoken/symbolic forms. While the spoken representations are expressed as semantic modes employing figures of speech or metaphors, the non-spoken representations include gestures, pictures, objects, diagrams, graphs, writings, symbols and icons. The concept mapping technique fits properly here as writings (concepts, words, prepositions); crosslinks and diagrams (circles, boxes, and connecting lines) are combined to visually display knowledge structures. Greca and Moreira (2000) posit that such representations of knowledge might provide us with better understanding of learning new conceptual structures. Similarly, studying these representations constructed by learners, would be better path to understanding and learning instead of trying to grasp events, systems or phenomena directly. Doing the latter may be impossible for some abstract, difficult or process-oriented concepts of physics such as waves hence the need to deploy the technique of concept mapping. Gabel (2003:74) contends that concept mapping helps students focus on the relationships among concepts so that students'long-term memories will accord with the scientific view.

Research evidences indicate that concept maps have been successfully applied in science as tool to facilitate the learning of science content (Tastan, Dikmenli & Cardak, 2008; Novak & Canas, 2008), improve achievement in physics (Okoronka, 2004; Alias, 2006; Luchembe,Chinyama&Jumbe, 2014); evaluation tool (Mintzes, Wandersee, Novak &Canas, 2000; Reiska, 2005;Chema&Mirza, 2013;Appoji&Shailaja, 2017); aid students comprehension and retention of science materials (Asan, 2007; Vodovozov&Raud, 2015); promote positive self-concept and attitudes towards science (Novak &Gowin, 1984; Okoronka&Ochai, 2016) and reveal unique thought processes (Cohen, 1987; Luchembe,Chinyama&Jumbe, 2014; Alebiosu& Michael, 2014). However, there is paucity of studies on the use of concept maps to promote and assess conceptual understanding in general and for difficult physics concepts in particular. This study was therefore designed to bridge this gap. The purpose of the study was to explore the use of concept map (for instruction and assessment) in enhancing conceptual understanding of some Nigerian senior secondary school students (SSS) in wave concepts in physics

2. The Problem

The wave concept has been identified as difficult (Dean, 1980; NERDC, 1994;Okoronka, 2004). This is attributed to the fact that the concept involves a function of two variables namely: distance and time in contrast to other concepts or situations encountered by students at the secondary school level which requires the function of a single variable only. Dean (1980) argues that this makes for a general weakness in understanding the fundamental ideas in wave by students. In other words, wave could be said to have considerable more conceptual content than is usually accorded in teaching it. Meanwhile, the ideas associated with waves are required by students for mathematics, chemistry and physics understanding. They also relate to everyday experience of students and are involved in their experimental and mathematical knowledge development (Okoronka & Taale, 2014).

How best then can the wave concept be taught in order to mediate the observed difficulty and enhance conceptual understanding of students? The researcher proposes that the concept mapping technique when used both as an instructional tool and assessment technique is capable of meeting these needs. The study addressed the following questions:

- Does concept mapping technique provide support for understanding to students in learning the difficult concept of waves in physics?
- What is the extent of relationship between scores obtained by students in multiple choice (achievement test, ATW) test and scores obtained in concept maps (CMSR) constructed by the same students.

3. Method and Instrument

The study adopted a pretest, posttest, control group, quasi-experimental design which made use of both quantitative and qualitative approaches to collect data. The quantitative aspect involved the use of achievement test scores obtained from the Achievement Test in Waves (ATW) and the scores from students drawn concept maps (experimental group only). The qualitative component of data involved analysis and scoring of concept maps drawn by individual subjects under the experimental group to infer understanding of the wave concepts under investigation (i.e. wave motion, wave profile and equation, wave types and properties, terms and definitions). The population of the study comprised all SSII physics students in Yola metropolis in government owned secondary schools. Two schools which satisfied the conditions of having qualified physics teacher and a West African Examination Council (WAEC) accredited physics laboratory were purposively selected from a total of 39 Senior Secondary Schools. The sample consisted of 130 subjects in two intact classes (one from each selected school) which were assigned to experimental (Group I) and control (Group II) respectively based on results of the pretest scores. The intact class with higher pretest mean score ($\overline{X}$= 4.26)was designated as the control group (N=62) while the intact class with the lower pretest mean score ($\overline{X}$=4.19) was assigned as the experimental group. The study lasted for six weeks in which one week was used for pretest and training (concept mapping group only), five weeks of instruction (treatment) and one week of posttest and assessment of students understanding through the drawn concept maps (experimental group only).

Two instruments were used for data collection namely: (i) Achievement Test in Waves (ATW) and (ii) Concept Map Scoring Rubric (CMSR).The final ATW contained 43 items of multiple choice type selected from past years of the West African Senior School Certificate Examination (WASSSCE) on the wave concepts of interest in the study. The instrument was subjected to the various validation procedures especially because they were adopted from different years of the same examination. The Guttmann split half was used to determine the alpha indices of the test (r = 0.78 and 0.65) for the first and second halves of the test respectively giving a Spearman Brown Prophecy Coefficient r=0.95 for the entire test. Each correctly answered item of ATW was scored one mark while a wrong answer attracted a score of zero.

The CMSR was used to assess the level of conceptual understanding of subjects under the experimental group who were made to construct individual concept maps at the end of each treatment session. Concept Maps drawn by students were scored using the following four steps explicated in CMSR in line with Liu (2014); Novak and Gowin (1984):

- Proposition scoring: Was there meaningful relationship(s) between two or more concepts indicated by the connecting line and linking words (propositions)?Score one mark for each as appropriate.
- Hierarchy scoring: Does the map show any hierarchical arrangement? In other words, was the concept map drawn at the top of more general concept while the one below is less general and more specific/less inclusive? – Score 5 marks as appropriate.
- Scoring cross link(s): Does the map indicate any main connection(s) between one arm of the concept map and another (Cross links)? Is the relationship shown significant and valid? Score 10marks for each cross link that is significant and valid.
- Are there specific events or objects mentioned as examples? Score one mark for each as appropriate.

The experimental group was exposed to treatment using concept mapping instructional strategy. Subjects were first exposed to training and practice sessions which involved clarification of meaning and definition of terms associated with concept maps. These include concept, proposition, relationships, hierarchies, cross links, specific examples and list of concepts (parking lot). Samples of concept maps drawn by experts on different topics were used to illustrate the structural representation/display of concept maps. Researcher drawn concept maps were then used to support teaching of wave concepts under the experimental group, while the control group was taught using the conventional lecture method. Both groups were taught by the researcher for the period of the study with the class teachers serving as research assistants. During the treatment session (experimental group only), subjects were made to list and copy the key concepts, words, phrases, or major ideas and given time to practice (individually) and draw concept maps to illustrate their understanding of the topic based on the list. Such maps were discussed and critiqued openly in class. The final score of individual subject in the concept mapping group is the average of the five maps scores obtained using the CMSR (see appendix II).

4. Data Analysis and Results

To address the question: Does concept mapping provide support for understanding in learning the difficult concept of wave? First, the pretest and posttest mean scores of subjects under experimental and control groups were compared as shown on Table 1.

Group	N	Pretest $\bar{X}$	Std. Dev.	Post test $\bar{X}$	Std. Dev.	Mean Gain
Expt. (Grp 1)	68	4.19	3.82	16.88	5.23	12.69
Control (Grp 2)	62	4.25	2.94	14.31	5.23	10.06

Table 1: Pretest and Posttest Means Scores and Standard Deviations of Experimental and Control Groups In ATW

Table 1 shows mean gain of 12.69 for group 1 compared to the mean gain of 10.06 for the control group 2. This is an indication that subjects in the experimental group had a higher mean gain than the control group subjects which could be attributed to the concept mapping treatment barring all other factors. The greater gain in mean scores by subjects under the experimental treatment condition is therefore taken as a direct consequence of the concept mapping instructional technique.
The mean gains recorded from pretest to posttest for the experimental and control groups were subjected to ANOVA using S.P.S.S version 19.0 as shown on Table 2.

Source	Type III Sum of squares	df	Mean Squares	F	Significance
Corrected model	933.660	3	311.220	14.087	0.000
Intercept	8450.868	1	8450.868	382.507	0.000
Pretest	717.431	1	717.431	32.473	0.000
Treatment	124.683	1	124.683	5.643	0.019*
Error	2783.784	126	22.093		
Total	35573.000	130			
Corrected Total	3717.423	129			

Table 2: Summary of ANCOVA of ATW Scores of Students by Treatment
** Significant P < 0.05*

From Table 2 [$F_{(1,129)} = 5.64$, $p < 0.05$]. This implies that there is significant mean difference between the pretest and posttest mean scores of the two groups in favour of the experimental group. This is further interpreted to mean that concept mapping instructional technique enhanced achievement of students more than the conventional lecture method. In addition, concept mapping technique was used to teach subjects under this group while they were equally made to draw individual concept maps (which are expressions of their conceptual understanding of concepts in focus). It could therefore further be interpreted that conceptmapping instructional technique enhanced the conceptual understanding of the subjects in the experimental group over and above that of the control group subjects. This is based on the fact that scores obtained by subjects based on their individually constructed concept maps revealed/expressed the individual levels of understanding of concepts taught. However, it needs to be further established that such significant improvement in achievement recorded by the experimental group (indicating enhanced conceptual understanding) was due to the use of concept mapping both to teach and assess subjects. This is necessary so as to infer the extent of support for understanding provided by concept mapping technique for subjects in learning the difficult concept of wave. This is done by comparing the gain in scores by subjects in treatment group 1 extracted simultaneously with scores obtained by subjects in concept maps drawn.

This led to the paired sample t-test analysis and comparison of the average scores obtained by subjects in the experimental group's self-drawnconcept maps (CMSR) with the mean gains of subjects (ATW) from pretest to pretest as shown on Table 3.

Source	N	Mean	Std. Dev.	df	t.	Sig (2 tailed)
CMSR	68	4.01	3.13	134	-11.68	0.000
ATW	68	12.53	5.13			

Table 3: Paired Sample T-Test of Individual Subject Concept Map Scores and Mean Gains

Results on Table 3 indicate that t_{134} = 11.68, p < 0.000. This implies that there is a significant difference when treatment (concept mapping instructional technique) is held constant between scores obtained by subjects using CMSR (expressing conceptual understanding) and mean differences in the pretest and posttest mean scores of the same subjects in ATW (multiple choice test).

To answer the question on the extent of relationship between scores obtained by subjects in achievement test (ATW) and scores obtained in concept maps drawn by the same subjects (expressing conceptual understanding via CMSR), linear regression analysis was conducted between the two variables. For the result of such analysis to be valid, certain initial conditions must satisfy, major among which is a significant F-ratio. This was fulfilled in Table 4

Model	Sum of square	df	Mean Square	F	Sig
Regression	17.157	1	17.157	136.496	0.000
Residual	16.843	134	126		
Total	34.000	135			

Table 4: Summary of ANOVA of Concept Map Scores (CMSR) and ATW Scores obtained by Subjects

Table 4 shows that [$F_{(1,134)}$ =136.496, p < 0.05]. This implies a significant F- ratio. Hence, linear regression was computed as shown on Table 5.

Equation	R	R^2	Adjusted R^2	df_1	df_2	Sig
	0.710	0.505	0.501	1	134	0.000

Table 5: Model Summary of Linear Regression of Scores Obtained by Subjects in Concepts Maps (CMSR) as Predictor of ATW Scores

Table 5 shows that $R_{(1,134)}$ = 0.71, P < 0.05 and $R^2_{adj.(1,134)}$ = 0.05. This implies that there is a significant high positive relationship between concept map scores of subjects and their ATW scores. It equally means that concept map scores (CMSR) of subjects could explain or predict 50% of multiple choice test (ATW) scores or vice versa.

5. Discussion

The study recorded significant difference in achievement between students taught using concept mapping instructional technique and those taught using conventional lecture method in favour of those taught using concept mapping. This result is in agreement with the findings of Alias and Shailaja (2017). Gabel (2003) had asserted that concept mapping is a successful technique which improves students understanding of science. Newton (2000) added that understanding can be inferred as indicator of the quality of science learning while Selvi (2012) submitted that the use of concept maps (as in this study) provides support for the learner to make various connections towards meaningful learning which in turn creates conceptual understanding as was recorded in this study.

Concept maps have been used in two ways in this study. First, as instructional tool (advance organizer) and second, as assessment tool. The purpose of its use for instruction was to enhance conceptual understanding of learners while the use for assessment was to infer students expressed understanding of concepts involved in the study. The superior achievement scores recorded by the concept mapping group of students over their lecture method counterparts could be attributed to the treatment. Hence, it can be said that concept mapping enhanced the conceptual understanding of students hence the superior achievement of the treatment group.

Furthermore, the significant difference of paired sample t-test recorded between CMSR scores (expressed conceptual understanding of students) and ATW scores (multiple choice test) when treatment was held constant, suggests that when concept mapping technique is applied and students are accessed via concept maps and multiple-choice test, there could be differences in achievement scores recorded. This can be explained by the fact that concept mapping instruction strengthens meaningful learning (Kinchin& Hay, 2000) while assessing students through concept maps offers better opportunity for them to express acquired knowledge (declarative). This is as opposed to the use of multiple choice test items which tend to encourage learning and assessment by rote. Concept maps drawn by students are indications of the extent to which they have been able to construct and integrate new concepts or knowledge into existing cognitive architecture by the explicit relationships between concepts drawn or shown. This finding agrees with Dahncke and Reiska (2008) who found that concept maps are suitable for testing students' declarative knowledge.

This study found a high positive significant relationship between the concept map assessment scores of subjects and their achievement scores on multiple choice test. This confirms the results obtained by Conradty and Bogner(2011) who recorded a high correlation between concept maps and other knowledge test as well as Bilici, Dogan and Avci (2015) who reported a significant and strong correlation between concept map scores and multiple-choice test. However, this finding is at variance with McGaghie, Crimmon, Thompson, Ravitch& Mitchell (2000) who did not prove any correlation between concept map scores and multiple-choice exam scores for medical and veterinary students' structural knowledge. There is need for further investigation in this area. This result could be explained by fact that students who acquired knowledge more meaningfully through treatment and equally had the privilege of drawing concept maps themselves; and were also assessed using concept maps, achieved higher on multiple choice tests. This could be attributed to the superior understanding which they acquired through their active engagement in all the activities of teaching, learning and assessment which tend to reinforce one another.

Furthermore, this study found that up to 50% of student's achievement in multiple choice test can be predicted or explained by scores obtained in concept maps or vice versa. This has implication for further researcher on the use of concept maps to measure and assess conceptual understanding as well as to determine the relationships between and among conceptual understanding, meaningful learning and multiple test achievement scores.

6. Conclusion and Recommendation

Based on the results of this study, it is concluded that concept mapping both as an instructional technique and assessment tool has a high potency to improve achievement, enhance conceptual understanding and assess understanding in a difficult concept (such as waves) in physics. It is therefore recommended that physics teachers especially at the secondary education level employ the tool of concept maps both for instruction and assessment as a way to enhance and assess both achievement and conceptual understanding of students.

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Appendix

Pretest, Posttest and Gain in Scores of Subjects (ATW) Taught Using Concept Mapping Technique

S/N	ATW (Pre)	ATW (Post)	Gain in scores
1	10	21	11
2	5	16	11
3	0	13	13
4	0	20	20
5	4	24	20
6	0	24	24
7	1	21	20
8	2	16	14
9	3	12	09
10	6	15	09
11	10	25	15
12	1	17	16
13	13	27	14
14	1	19	18
15	5	10	05
16	0	9	09
17	12	20	08
18	3	17	14
19	7	20	13

20	1	15	14
21	7	23	16
22	1	19	18
23	4	20	16
24	8	25	17
25	4	18	14
26	10	21	11
27	4	5	01
28	5	11	06
29	5	18	13
30	0	9	09
31	1	9	08
32	2	12	10
33	7	10	03
34	7	19	12
35	4	15	11
36	5	11	06
37	2	12	10
38	1	22	21
39	1	17	16
40	1	21	20
41	5	11	06
42	12	21	09
43	4	10	06
44	2	17	15
45	8	21	13
46	1	16	15
47	3	15	12
48	13	20	07
49	11	19	08
50	6	11	05
51	1	28	27
52	0	15	15
53	1	11	10
54	1	14	13
55	3	17	14
56	2	19	17
57	10	16	06
58	4	15	11
59	2	19	17
60	2	20	18
61	0	16	16
62	0	12	12
63	0	22	22
64	3	13	10
65	4	11	07
66	2	14	12
67	0	25	15
68	14	25	11

Table 6

CMSR Scores of Subjects taught Using Scores of Concept Mapping

S/N	Scores
1	2
2	2
3	1
4	2
5	2
6	14
7	2
8	0
9	0
10	0
11	08
12	4
13	6
14	5
15	5
16	0
17	0
18	0
19	3
20	5
21	15
22	5
23	7
24	5
25	4
26	4
27	3
28	3
29	0
30	7
31	6
32	8
33	3
34	2
35	5
36	8
37	7
38	0
39	0
40	0
41	1
42	6
43	5
44	2
45	6
46	6
47	7
48	9
49	1
50	0
51	5
52	5
53	4

S/N	Scores
54	7
55	7
56	5
57	8
58	1
59	2
60	5
61	4
62	4
63	4
64	4
65	3
66	3
67	1
68	4

Table 7