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Examination of Elementary Teachers' Views about Concept Maps

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Abstract

One of the teaching methods that are carried out to make teaching-learning process more effective is concept mapping. Learners can incorporate new knowledge into their prior knowledge framework by utilizing concept mapping. Furthermore, representation and organization of the knowledge through concept maps, helps retention and recall. Thus concept maps facilitate meaningful learning by organizing knowledge in cognitive structure and encourage creative thinking. Concept maps constructed by the teachers, enable students identify and explore the structure and the nature of knowledge. The use of concept maps can also assist teachers in evaluating the process of teaching. This study aims to investigate the elementary teachers' views on concept maps by using an open-ended questionnaire which is carried out with 24 elementary teachers. Before conducting the questionnaire teachers have

been instructed about concept maps and they constructed concept map examples. The findings indicate that elementary teachers generally perceive concept maps as a useful, effective, practical tool and they highlighted concept maps as important since they provide feedback. An important implication of this study is that there is a need for teachers to know how to teach concept map construction, to associate the concept maps into their lessons and into the evaluating process.

Keywords: Concept maps, Teachers' views, Meaningful learning

1. Introduction

The desire to improve achievement through more effective instructional strategies and the increasing awareness of the importance of learner-centeredness in the teaching-learning process has directed a lot of attention to understanding how learners learn and how to help them learn concepts (Jegede, Alaiyemola, & Okebukola, 1990). A significant number of studies have employed the concept map as a metalearning strategy in an attempt to help students "learn how to learn" (Wallace & Mintzes, 1990). Concept maps were developed by Novak on the basis of Ausubel's (1968) assimilation theory of cognitive learning. The fundamental idea in Ausubel's cognitive psychology is that learning takes place by assimilation of new concepts and propositions into existing concept and propositional frameworks held by the learner (Novak & Canas, 2008). Based on assimilation theory, concept maps facilitate deep understanding as opposed of rote learning by making conceptual relationships explicit, by serving as advance organizers for subsequent learning, and by highlighting misconceptions and alternative frameworks (Edmondson, 1994). Concept mapping also has been reported to aid collaborative learning, and to improve students' problem-solving ability (Buntting, Coll, & Campbell, 2006). As students make concept maps they reorganize newly acquired and existing concepts into a hierarchical network and depict relationships among the concepts. At the same time relationships are clarified and integrated into larger knowledge structures. The task requires a student to think in multiple directions and to switch back and forth between different levels of abstraction (Briscoe & LaMaster, 1991). Students' concept maps reveal to students themselves and to their teacher much more detailed knowledge than they earlier imagined possible to know about their learning (Ahlberg & Ahoranta, 2008). Constructing concept maps gives students improved confidence of the content: they feel that they can master information, for example, by linking it to previous readings, incorporating it with more ease into their knowledge frame. For teachers, maps are useful if they are constructed to reveal the connections between the various aspects of a subject, thus opening the opportunity to more examples and clarity in the teaching (Cicognani, 2000).

Concept mapping has also been used to reveal the extent of reorganization of a students' knowledge structure (Borda, Burgess, Plog, DeKalb, & Luce, 2009). Wallace and Mintzes (1990) suggest that concept mapping offers a valid and useful mechanism for looking at changes in cognitive structure. According to Novak (1990) concept maps were not only a useful tool to represent changes in the knowledge structure of students over time, but also helped them to "learn how to learn". Through concept mapping, students were able to organize their knowledge from a number of sources (Briscoe & LaMaster, 1991) moreover restructure and represent what they know (Novak, 2010). Also it serves as a tool to help learners organize their cognitive frameworks into more powerful integrated patterns (Jegede, Alaiyemola, & Okebukola, 1990).

Concept maps are defined by Novak and Canas (2008) as graphical tools for organizing and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connected line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship

between the two concepts (Novak & Canas, 2008).

The process of constructing concept maps requires critical and analytic thinking (Moni & Moni, 2008). Novak describes concept mapping as:

> "A process that involves the identification of concepts in a body of study materials and the organization of those concepts into a hierarchical arrangement from the most general, most inclusive concept to the least general, most specific concept." (Malone & Dekkers, 1984).

Concept maps can be constructed in several ways. A simple method is to supply students with a list of related concepts and have them construct a map, placing the most inclusive, most general concept at the top and then showing successively less inclusive concepts at lower positions on a hierarchy. Learners must decide how best to represent the concepts hierarchically and the words to use to link concepts together. Another method is to have students identify key concept words in text of some kind and then to use these concepts to form a hierarchical map (Novak, Gowin, & Johansen, 1983).

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. Cross-links are relationships or links between concepts in different segments or domains of the concept map and help to see how a concept in one domain of knowledge represented on the map is related to a concept in another domain shown on the map (Novak & Canas, 2008). In general, the greater the number of valid links between concepts, the more sophisticated the map is considered to be (Novak & Gowin, 1984). The technique therefore focuses on conceptual organization and integration and gives students a way to explicitly link and organize concepts (Buntting, Coll, & Campbell, 2006). So concept mapping allows students to connect concepts in a variety of relationships (Briscoe & LaMaster, 1991).

According to Novak and Canas (2008) concept mapping is so powerful for the facilitation of meaningful learning while it serves as a kind of template or scaffold to help to organize knowledge and to structure it, even though the structure must be built up piece by piece with small units of interacting concept and propositional frameworks. By summarizing the subject using keywords and linking these keywords to create a map of relationships, individuals are able to clarify for themselves what is involved in a certain subject and be more effective in using that information. The information collected in the map is easily accessed by looking at how the relationships between words or concepts have been outlined (Cicognani, 2000).

An advantage of using concept mapping as a learning technique lies in the possibility to have a visual representation of information (Cicognani, 2000).Visual representation allows the development of a holistic understanding that words alone cannot convey, because the graphical form allows representations of parts and whole in a way that is not available in sequential structure of text (Asan, 2007). With the visual representation of keywords on a map, a learner is also able to refine language and vocabulary, identify the key issues of a text, organize these key issues into a meaningful chart, re-use the map in the future with a reasonable success (Cicognani, 2000).

Since 1975, concept mapping has become an important tool to help students learn to learn meaningfully, and to help teachers become more effective teachers (Novak, 1990). Novak (1991) suggests that concept maps constructed by students help them to learn meaningfully. Whenever teachers construct a concept map they gain new insights into the meaning of that subject matter. By using concept maps in curriculum planning and case development, teachers can promote learning by making material conceptually coherent and thus easier for students to integrate (Edmondson, 1994). As a constructivist-based tool that supports meaningful learning, the concept map holds considerable potential to enhance teachers' classroom instruction (Rye, 2000). As the theory of meaningful learning suggests, concept mapping also shows that student prior-knowledge quality is a good predictor of knowledge at the end of a course. Understanding what students know to begin with is necessary if teachers want to teach meaningfully (Hay & Kinchin, 2008). It is often difficult for teachers to know what students do and do not understand, while learning is a private and individual process. Unlike traditional forms of assessment and instruction, concept mapping allows teachers the opportunity to both observe how extensive and integrated a student's conceptual knowledge is, and share their own conceptual understanding with students. Moreover, concept mapping as a form of assessment offers teachers the opportunity to recognize a student's misconceptions, impediments to learning that traditional assessments may not detect (Walker & King, 2002). Many recent studies indicate that educators need to empower learners by helping them organize and use carefully developed hierarchical knowledge structures (Novak, 1993). In implementing the use of concept mapping, it was found that there was a need for the teacher to model the construction of concept maps (Buntting, Coll, & Campbell, 2006). According to Kinchin and Alias (2005) creating concept maps can be introduced to teachers at any stage of their professional development. Consequently, it can be argued that concept maps are considerably useful instructional tools for teachers and students as well. Therefore it is important to reveal the awareness of teachers on significance of concept mapping. For this rationale, this study aims to investigate elementary teachers' views about concept maps.

2. Method

An exploratory research design is used in order to collect detailed information about teachers' views. To do this, open-ended questions were applied and their opinions on concept mapping received. A total of 24 elementary teachers from different regions and cities of Turkey participated in the study. Teachers' experience in the profession varies between two and 21 years. Before conducting the questionnaire teachers have been instructed about concept maps and they constructed concept map examples. The items in the questionnaire were developed in order to elicit teachers' views deeply on concept mapping, its applicability, advantages and difficulties. The data were arranged by reducing the statements and analyzed thematically. Furthermore relevant quotations from teachers' responses were presented.

3. Findings

The findings of the study were obtained by reducing the statements in the responses given to each open-ended question and then they were grouped according to frequency of occurring. In Table 1, frequencies and percentages for the statements involved in the responses given to

the first question are presented. The aim of this question is to elicit the teachers' opinions deeply about concept maps.

Table 1. Frequencies and percentages of teachers' views on first open ended question.

Question 1: What do you think about concept maps? Please explain.		
Statements	**f**	**%**
Concept map increases the retention of learning.	10	18.9
Concept map is an effective teaching tool.	5	9.4
Concept map facilitates learning.	6	11.3
Concept map helps to create relationships among concepts.	6	11.3
Concept map makes learning fun.	3	5.7
Concept map is more suitable for 4^{th} and 5^{th} grades.	2	3.8
Concept map allows the visualization of knowledge.	2	3.8
Concept map is a useful evaluation tool.	3	5.7
Concept map prevents misconceptions.	1	1.9
Concept map may be difficult at first stage.	2	3.8
Concept map concretes the abstract concepts.	1	1.9
Concept map facilitates planning.	1	1.9
Concept map motivates learner to think.	2	3.8
Concept map is not suitable for assessment.	1	1.9
Concept map is a useful/necessary/effective technique.	8	15.1

As can be seen in Table 1, the teachers most frequently stated that the concept maps increase the retention of learning. Though the teachers widely believe that concept map is an effective/useful method that helps create relationships among concepts, and facilitates learning, they think that at first stage it can be difficult to use them. Although there are some teachers thinking that concept maps are useful in identifying misconceptions and misunderstandings, there is one teacher thinking they are not suitable for assessment. Some quotations from the teachers' responses given to the first question are presented below:

> "I think that concept maps facilitate learning and increase the retention of learning."
>
> "I think they constitute an effective strategy that has the potential of helping us to explain the relationship among the concepts and to prevent misconceptions."
>
> "I found concept maps useful, but at first stage, they can be difficult to use for students."
>
> "I consider them a method which may help students to keep the concepts for a longer time in their memory and evaluate them better after the instruction."

Second question aims to investigate whether the teachers find concept maps applicable in the instructional environment and why they think so. Frequencies and percentages for the statements involved in the teachers' responses to this question are presented in Table 2.

Table 2. Frequencies and percentages of teachers' views on second open ended question.

Question 2: Do you find concept maps applicable in the learning environment? Why?		
Statements	**f**	**%**
Concept map is a useful method.	11	32.4
Concept map is fun to apply.	3	8.8
Concept map renders students more active.	4	11.8
Concept map is inexpensive.	1	2.9
Concept map is easy to use.	4	11.8
Concept map presents brief and clear information.	1	2.9
At first stages, it is difficult to apply.	2	5.9
Concept map can be used to determine prior-knowledge.	2	5.9
Concept map can be used to evaluate teaching.	2	5.9
Concept map requires some preparation.	2	5.9
Concept map can be used with students from every grade.	2	5.9

Eighty three percent of the teachers participating in the study stated that they certainly find concept maps applicable in the learning environment. While one of the teachers stated that it may vary depending on the nature of course, there are some teachers stating that it can be difficult to use them with small children. In general, the teachers think that concept maps are easy to use, inexpensive and entertaining. Some quotations from the teachers' responses given to the second question are presented below:

"It is an easy and inexpensive method."

"I find it applicable. Concept maps make up a very useful strategy that teachers can use during the introduction section to identify students' prior knowledge or they can use at the end of the lesson to evaluate."

"They are really useful on condition that some preparations are made."

"They can be used for students from every grade level by simplifying them."

Third question aims to reveal at which stage of the lesson the teacher think of using concept maps. Frequencies and percentages of the statements involved in the teachers' responses to this question are presented in Table 3.

Table 3. Frequencies and percentages of teachers' views on third open ended question.

Question 3: At which stage of your lessons do you think of using concept maps? Why?		
Statements	**f**	**%**
At the introduction to the lesson/while introducing the topic.	11	25.6
At the end of the unit for evaluation.	12	27.9
At the end of the lesson for summary.	3	7
At the end of the lesson for revising.	3	7
While teaching the lesson.	7	16.3
They can be used at every stage.	3	7
When certain period of time passed after the teaching of the lesson to test the retention.	1	2.3
I do not use them at the introduction stage.	1	2.3
I do not use them for assessment.	2	4.7

The teachers stated that they generally prefer to use concept maps at the end of the lesson for evaluation, summary, or revision. While the number of teachers stating that they prefer to use concept maps for introduction to the lesson, one of the teachers stated that he/she does not prefer to use them for introduction. There are some teachers who do not want to use concept maps for assessment and there were some other teachers who want to use them at every stage of the lesson. Some examples of quotations from the teachers' responses given to the third question are presented below:

> "I employ them to determine the readiness level of the students at the introduction to the lesson or to improve the retention of the concepts at the end of a unit."
>
> "They can be used at every stage ranging from introduction to development and evaluation."
>
> "I make use of them at introduction to lesson to create awareness of what students know and do not know; moreover, at the evaluation stage, I use them to learn and to show students to what extent they have learned."
>
> "If I prepare them myself, I use them at introduction, but if students themselves create them, I use them after giving students prior knowledge but I do not use them for assessment."

Fourth question asks the teachers whether they use the concept maps which they themselves constructed or they prefer to use the concept maps constructed by students. Frequencies and percentages for the statements involved in the teachers' responses to this question are presented in Table 4.

Table 4. Frequencies and percentages of teachers' views on fourth open ended question.

Question 4: Do you prefer to use the concept maps constructed by you or by your students in your lessons? Why?		
Statements	**f**	**%**
Concept maps constructed by students.	12	50
Concept maps constructed together with students.	3	12.5
Both teacher-constructed and student-constructed concept maps.	9	37.5

Half of the teachers stated that they prefer to use concept maps constructed by students in their lessons. They claimed that when students themselves constructed concept maps, they become aware of their knowledge level and they can realize more meaningful and permanent learning. Some other teachers, on the other hand, stated that they prefer to construct together with students under their guidance, and others stated that they prefer to use both teacher-constructed and student-constructed concept maps. Some quotations from the teachers' responses given to the fourth open-ended question are presented below.

> "I prefer the ones constructed by students. Concept maps constructed by students based on their own lives, experiences and learning processes will be more effective."
>
> "I prefer to use concept maps constructed together with the students under my guidance. I think learning occurs while constructing the maps."
>
> "While I am introducing this method to my students, I may share my own samples with them. But then I prefer to get students to construct their own concept maps to make them actively involved in the process."

Fifth question asks teachers what they think about the difficulties that may be encountered by themselves and their students while constructing concept maps. Frequencies and percentages for the statements involved in the teachers' responses to this question are presented in Table 5.

Table 5. Frequencies and percentages of teachers' views on fifth open ended question.

Question 5: While constructing concept maps at which points do you think you and your students will have difficulty? Why?		
Statements	**f**	**%**
While determining the concepts.	9	25
While creating relationships among the concepts.	7	19.4
While setting up the hierarchy.	6	16.7
While drawing the borders of the topic.	2	5.6
While writing the propositions.	4	11.1
While adapting them to students' level.	2	5.6
They can be complicated.	2	5.6
They are not difficult.	4	11.1

The teachers think that students most probably will have difficulties while selecting the concepts, determining general and specific concepts, and accordingly, setting up the hierarchy. Some teachers are worried about the possibility of going beyond the borders; some others think that it can be difficult to adapt concept maps to the level of students. The percentage of the views that writing proposition can be difficult is 11. And the rate of the views that concept maps can be complicated is 6%. Some quotations from the teachers' responses given to the fifth question are presented below.

> "While constructing concept maps, I believe that students will mostly have difficulties in creating relationships among the concepts."
>
> "They can be complicated. Students may have some difficulties while writing propositions."
>
> "I think the most difficult aspect of the process is sequencing the concept in a hierarchical order."
>
> "Students may have some difficulties in understanding relationships among the concepts. They may have hard times in finding sub-concepts."

4. Results and Discussion

Although many of the studies support concept mapping as a teaching and learning strategy, they mainly focus on the use of concept mapping as a tool to investigate student understanding rather than evaluating its availability by teachers. It is therefore of interest of this study to investigate the thoughts, feelings, and beliefs of teachers using concept map as a teaching/learning tool.

Results of this study indicated that elementary teachers generally perceive concept maps as a useful, effective and practical tool. And also they stated that concept mapping facilitate teaching process and increase retention of learning. Moreover they highlighted concept maps as important since they provide feedback. The participants of the study were of the opinion that representation and organization of knowledge through concept maps, helps retention and recall. Some of the teachers perceived concept maps easily applicable and amusing on the other hand a few of them considered concept mapping as complicated. Generally teachers stated that using concept maps at the beginning or at the end of the lessons is more appropriate. Besides, most of them were in favor of student-constructed maps. Teachers supposed that while constructing concept maps students have difficulty at relating the concepts and determining the propositions. According to another result, both of teachers and students have difficulty at arranging the hierarchical structure of concept maps.

Some of the results of this study have similarities with related studies. For example, Hay and Kinchin (2008) have shown that concept mapping is quick and easy to use and has utility even among very large student groups. Also they suggested that concept mapping is a practical method for teaching. In another study Novak (1991) indicated that concept maps constructed by students help them to learn meaningfully. When teachers construct a concept map they gain new insights into the meaning of that subject matter. Yet another study result revealed that teachers commonly reported concept mapping helps them to see expressions of

creative thinking on the part of their students (Novak, Gowin, & Johansen, 1983). According to Horton et al., (1993) there is evidence that concept maps can help teachers become more effective. For elementary, secondary and college teachers the concept map offers an opportunity to significantly broaden the range of evaluation practices in current use, which encourage meaningful learning (Novak & Gowin, 1984). Another study result suggested that concept mapping is a valuable formative assessment that provides substantial benefits to students, in terms of motivation and critical thinking skills, while exacting minimal cost from the teacher in terms of time and material (Walker, 2002). In general, it seems that these results support the use of concept mapping as learning, teaching and evaluating tool by teachers in the instructional environment. The results of this study indicate that elementary teachers are aware of the importance of concept mapping and they are in favor of using concept maps. But teachers have deficiency about the theory underlying concept maps and also they are not sufficiently familiar with the use of concept maps. It can be concluded that there is a need for teachers to know how to teach concept map construction and to associate the concept maps into their lessons and into the evaluating process.

References

Ahlberg, M., & Ahoranta, V. (2008). Concept maps and short-answer tests: Probing pupils' learning and cognitive structure. In A. J. Cañas, P. Reiska, M. Åhlberg, & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators*, Proceedings of the Third International Conference on Concept Mapping. Tallinn, Estonia & Helsinki, Finland.

Asan, A. (2007). Concept mapping in science class: A case study of fifth grade students. *Educational Technology & Society, 10*, 186-195.

Ausubel, D. P. (1968). *Educational Psychology, A Cognitive View.* New York, Holt, Rinehart, Winston.

Borda, E. J., Burgess, D. J., Plog, C. J., DeKalb, C. N., & Luce, M.M. (2009). Concept maps as tools for assessing students' epistemologies of science. *Electronic Journal of Science Education, 13*, 160-185.

Briscoe, C., & LaMaster, S. U. (1991). Meaningful learning in college biology through concept mapping. *The American Biology Teacher, 53*, 214-219.

Buntting, C., Coll, R. K., & Campbell, A. (2006). Students views of concept mapping use in introductory tertiary biology classes. *International Journal of Science and Mathematics Education, 4,* 641-668. http://dx.doi.org/10.1007/s10763-005-9014-7

Cicognani, A. (2000). Concept mapping as a collaborative tool for enhanced online learning. *Educational Technology & Society, 3*, 150-158.

Edmondson, K. M. (1994). Concept maps and the development of cases for problem-based learning. *Academic Medicine, 69*, 108-110. http://dx.doi.org/10.1097/00001888-199402000-00004

Hay, D., & Kinchin, I. (2008). Using concept mapping to measure learning quality. *Education & Training, 50*, 167-182. http://dx.doi.org/10.1108/00400910810862146

Horton, P. B., McConney, A. A., Gallo, M, Woods, A. L., Senn, G. J., & Hamelin, D. (1993). An investigation of the effectiveness of concept mapping as an instructional tool. *Science Education, 77*, 95-111. http://dx.doi.org/10.1002/sce.3730770107

Jegede, O. J., Alaiyemola, F. F., & Okebukola, P. A. O. (1990). The effect of concept mapping on students' anxiety and achievement in biology. *Journal of Research in Science Teaching, 27*, 951-960. http://dx.doi.org/10.1002/tea.3660271004

Kinchin, I. M., & Alias, M. (2005). Exploiting variations in concept map morphology as a lesson-planning tool for trainee teachers in higher education. *Journal of In-service Education, 31*, 569-592. http://dx.doi.org/10.1080/13674580500200366

Malone, J., & Dekkers, J. (1984). The concept map as an aid to instruction in science and mathematics. *School Science and Mathematics, 84*, 220-231. http://dx.doi.org/10.1111/j.1949-8594.1984.tb09543.x

Moni, R. W., & Moni, B, K. (2008). Student perceptions and use of an assessment rubric for a group concept map in physiology. *Advances in Physiology Education, 32*, 47-54. http://dx.doi.org/10.1152/advan.00030.2007

Novak, J. D., Gowin, D. B., & Johansen, G. T. (1983). The use of concept mapping and knowledge vee mapping with junior high school science students. *Science Education, 67*, 625-645. http://dx.doi.org/10.1002/sce.3730670511

Novak, J. D., & Gowin, D. B. (1984). *Learning How to Learn*. Cambridge, England: Cambridge University Press.

Novak, J. D. (1990). Concept mapping: A useful tool for science education. *Journal of Research in Science Teaching, 27*, 937-949.

Novak, J. D. (1991). Clarify with concept maps. *The Science Teacher, October,* 45-49.

Novak, J. D. (1993). How do we learn our lessons? *The Science Teacher, March,* 50-55.

Novak, J. D., & Canas, A. J. (2008). The Theory Underlying Concept Maps and How to Construct and Use Them, *Technical Report IHMC CmapTools* 2006-01 Rev 01-2008, Available: http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf

Novak, J. D. (2010). *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations* (2nd ed.). NY: Routledge.

Novak, J. D., & Canas, A. J. (2010). The universality and ubiquitousness of concept maps. In J. Sánchez, A. J. Cañas, J. D. Novak (Eds.), *Concept Maps: Making Learning Meaningful,* Proceedings of Fourth International Conference on Concept Mapping, Viña del Mar, Chile.

Rye, J. A. (2000). Electronic concept mapping as a professional development focus for health sciences and technology academy (hsta) teacher-participants. *Proceedings of the Annual Meeting of the Association for the Education of Teachers in Science,* January 6-9 2000, Akron, OH.

Stewart, J., Vankirk, J., & Rowell, R. (1979). Concept maps: A tool for use in biology teaching. *The American Biology Teacher, 41*, 171-175.

Walker, J. M. T., & King, P. H. (2002). Concept mapping as a form of student assessment and instruction. *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.* Montreal, Canada.

Wallace, J. D., & Mintzes, J. J. (1990). The concept map as a research tool: Exploring conceptual change in biology. *Journal of Research in Science Teaching, 27*, 1033-1052.