Concept Mapping for Eliciting Students' Understanding of Science

MEENA KHARATMAL

ABSTRACT

Students' understanding of science has been of considerable importance in the area of science education research. It tries to focus on issues such as conceptual understanding, teaching of science, students' knowledge structure, tools that can aid in their understanding of science, etc. Concept map is one such tool that is used to elicit students' knowledge and teaching and learning in a given domain. Concept maps are two-dimensional, hierarchical and node-link diagrams that depict knowledge. This article presents a review of concept maps in science education research with an illustration of a case study on the effectiveness of concept maps for eliciting students' knowledge structure from the domain of cell biology. The study used two different methods— description and concept maps – for depicting students' knowledge. The study depicts a significant increase in the depiction of concepts and propositions using the concept mapping method as compared to the description method.

Introduction

Science education research has been influenced by the cognitive science paradigm which in itself is an inter-disciplinary field informed by psychology, information processing, neuroscience, education, etc. One of the most prominent areas of the research is that of students' understanding of science. In India, the research has focussed on students' understanding, their alternative conceptions, reasoning ability, classroom learning practices, teaching science, etc at various

*Homi Bhabha Centre for Science Education, (TIFR), V.N. Purav Marg, Mumbai 400 088. E-mail: meena@hbcse.tifr.res.in

levels (Chunawala, 2006). On the issues of learning and knowledge, the *National Curriculum Framework* (NCF) 2005 (NCERT 2005, pp. 12-34) reviews the various validities in science education such as *cognitive validity* and *content validity* among others. These validities demand that the content and the pedagogical practice of the curriculum should not be only scientifically accurate but also pertinent with the age of the child. In addition, the NCF describes the structure of knowledge as a set of propositions comprising of concepts and relations, i.e. nodes and links, which are considered as the building blocks of knowledge. Various forms of tools of knowledge representation are applied to elicit students' understanding, depict conceptual changes, point alternative conceptions, etc. Such tools aid in depicting students' understanding and are considered guide for teachers to evaluate the students' understanding. One such potential tool – **Concept Map** is used to capture this important aspect.

Concept maps are two-dimensional graphical representation of a knowledge in a given domain (Novak & Gowin, 1984) developed for achieving meaningful learning in classroom (Ausubel, et.al. 1978). Meaningful learning, as explicated by Ausubel, is the non-arbitrary, non-verbatim, substantive incorporation of new ideas into learner's framework of knowledge, while rote learning is arbitrary, verbatim, non-substantive in nature. Concept mapping has been developed based on the cognitive assimilation theory for classroom learning proposed by Ausubel with the fundamental assumption: "*The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly*" (1978). The advantages of meaningful learning are that the concepts are retained longer, subsequent learning becomes easier, thus enabling to build a useful knowledge structure which is valued over rote understanding. Concept maps give a global picture of students' conceptual understanding rather than a piecemeal depiction of isolated facts (Mintzes, Wandersee & Novak, 1998).

Concept Map

Typically a concept map is a representation of *concepts and linking words* in a hierarchical, dendritic pattern arranged in a top-bottom manner depicting the differentiation of knowledge from a general level to specific level that have examples at the terminal end. *Concepts* can be defined as perceived regularities in objects or events that are designated by a sign or symbol. For example, the term '*House*' is a concept that refers to walls, floors, bricks, used for living, etc. *Linking*

words are used to provide meaningful relationships between two concepts. For example, the linking words '*made of*' is used to frame a proposition '*A House is made of bricks*'; another linking word '*used for*' is used to frame a proposition '*House is used for living*', etc. Concepts are the unit of thought and attain meaning by making connections with other concepts by using the linking words. Therefore, in a concept map, the concepts and linking words are the two main components of knowledge. As an illustration, Figure 1 shows a concept map on *Living Organisms*.
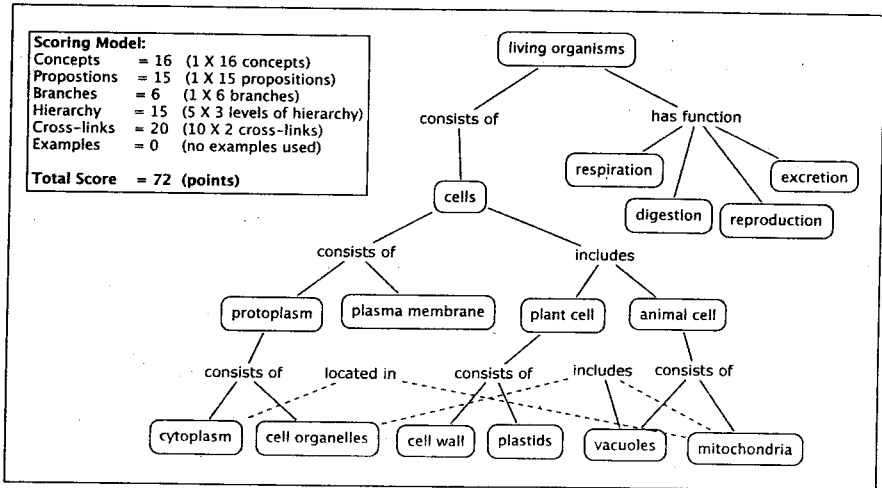
Fig. 1: *A concept map on living organisms with a suggested scoring model.*

Constructing Concept Maps

The concept maps can be drawn using paper and pencil, blackboard, post-it notes, and computer software. The concept maps are user-friendly and easy to draw. To begin with, the mapper selects a topic of interest and reads the topic. For example, living organisms, cell division, etc. While reading, around 10-15 major concepts are identified. For instance *cell, nucleus, unicellular, multicellular*, etc. The concepts are enclosed within an ellipse outline. These concepts are arranged from general (superordinate) to specific (subordinate) levels. This is followed by labelling links by drawing lines to these concepts. These links provide meaning to the concepts, and few such linking words are: *consists of, includes, surrounded by, has function, example*, etc. which are written on the lines connecting the concepts. A good

concept map depicts a hierarchical and dendritic organisation of concepts displaying the progressive differentiation of knowledge. Wherever possible a single general concept can be branched out to atleast two-three specific concepts. This would portray the breadth and depth of the knowledge. Using cross-links to various concepts are highly encouraged. A cross-link is a labeled link of concepts within cross-domains in a concept map depicting integrative reconciliation. In order to stand out the cross-links these are drawn as dotted lines. The concept maps can have examples at their terminal end which are labelled using the linking word, *e.g.* and are enclosed in dotted ellipse. The examples are actual instances such as *Ganges, Himalayas*, etc. Based on these above elements a scoring model has been suggested as shown in Figure 1.

A concept map depicts four main cognitive processes such as – **subsumption, progressive differentiation, integrative reconciliation, superordinate learning** – proposed by Ausubel that helps to build a knowledge framework during classroom learning. Subsumption is the core principle of Ausubel's theory. During subsumption, the learners links new knowledge or concepts which are more specific, or less inclusive, to a more general concept. Superordinate learning occurs when a new idea is relatable to specific subordinate ideas in the existing cognitive structure. Progressive differentiation states that learning, retention, and organisation of knowledge is hierarchical in nature. During differentiation, elaboration and clarification of meaning occurs. Integrative reconciliation occurs when there arises some similarities and/or differences between related concepts across domains.

Concept map is also considered to dwell on issues of meaning making, understanding conceptual change and knowledge structure and emphasising on quality of knowledge which are highlights of the prevalent Human Constructivist Era (Mintzes, Wandersee and Novak, 1998). While there exists several other graphical tools for knowledge organisation (Fisher, et. al. 2000) such as Concept Circle Diagrams (developed by Wandersee), Knowledge Vee (by Gowin), SemNet (by Fisher), the concept maps developed by Novak and his colleagues have been used extensively for the past three decades in research studies for depicting and evaluation of knowledge.

Advantages of Concept Map

Concept maps have been useful tool as diagnostic, pedagogical, assessment, data collection, knowledge organisation tool. Concept

maps have been effective in eliciting knowledge, depicting misconceptions, tracing conceptual changes in students' understanding of a domain. As a pedagogical tool, concept maps help to see the effects in teaching on learning, and to negotiate the concept meaning with the learner, as assessment tool, concept maps serve as a formative or summative assessment tool, as a knowledge oragnisation tool the concept maps help as a research tool in investigating of students' understanding, their knowledge structure, allows for sharing of ideas.

Research on Concept Maps

For Learning

Concept maps have been used effectively for knowledge elicitation in research studies for meaningful learning, for documenting the conceptual change in students' knowledge structure in longitudinal as well as cross-age studies, for comparing the differences in knowledge structuring between experts and novices. In a review study based on about 150 studies on concept mapping, the authors concluded that concept mapping helps students gain meaningful learning, and enhances the integration and retention of knowledge (Mintzes et. al., 1997, pg. 428). Concept mapping technique is used for recording the changes before and after instruction. By comparing successive concept maps researchers documented and explored the conceptual change in a group of biology students as they gained mastery of the domain (Carey, 1986; Wallace & Mintzes, 1990). The studies indicate a change in the use of more number of critical concepts and propositions, more intricate hierarchical structure, branching patterns and occurrence of cross-linkages (Wallace & Mintzes, 1990, pg. 1038). Concept maps are used to depict expert – novice differences in knowledge structures on the basis of the frequency of concept descriptors and propositions that appear in a map (Mintzes, 2007). Longitudinal studies on students' understanding of the particulate nature of matter (from grade 2 to 12) were conducted using concept maps (Mintzes et. al., 1998). The maps revealed students' knowledge structures over a period of time and the maps served to record the changes in their conceptual framework. Thus, concept mapping has been a very useful tool to elicit students' understanding and to study the nature of restructuring in cognitive development, particularly in the classroom context.

For Assessment

The other relevant areas that concept mapping have been found to be useful are curriculum planning, assessment, etc. One of the ways of assessing students' knowledge structure is through knowledge elicitation, which can be accomplished by interviews, open-ended questions, multiple-choice tests, etc. The educative episodes involve *learner, teacher, domain of knowledge, social milieu* and *assessment* all of them interacting with each other (Novak, Mintzes and Wandersee 2000). Assessment in education is equally of significance as learning is. In an objective assessment, with the help of clues a student is able to recall, choose and provide a correct answer to a question. If we want to assess student's understanding of a domain it can be done by eliciting the knowledge of the student about the domain. Students' knowledge structure of a domain can be elicited in different ways such as — word associations to concepts, concept similarity, concept maps (Ruiz-Primo and Shavelson, 1996, p. 570). It is known that the subject domain of science is conceived as a rich set of relations among concepts and therefore eliciting this set of relations from students will help to assess students' knowledge structure. The earliest attempts in diagnosing students' knowledge frameworks were by Jean Piaget using clinical interviews. In the current science education literature, several kinds of assessment techniques are recorded for investigating students' knowledge structure. Some of these are — structured interviews, knowledge Vee, concept circle diagram, image based test, concept maps, semnet. Using concept maps by providing cues or constraints, falls very close to the scale of high-directed on the degree of directedness continuum as proposed by Ruiz-Primo (2004).

Considering the potentialities of concept maps in science education research, a research study has been conducted to check the effectiveness, feasibility of concept maps in the Indian context. The following part of the article elaborates on this research study.

The Study

Fifteen students from Class VIII from the age groups of 12-14 were randomly selected from a local school in Mumbai for the research study. The domain chosen was a chapter on *Cell Structure and Function* from the Science Textbook of National Council of Educational Research and Training (NCERT) curriculum (NCERT 2004, pp. 118-26). The objective of the study was to examine the effectiveness of the concept mapping method over the description method of depicting knoweldge.

TABLE 1
List of Seed Concepts and Seed Linking Words

Seed concepts	Seed linking words
cell	consists of
living organisms	includes
nucleus	surrounded by
unicellular	has function
amoeba	has size
energy-production	located in
cytoplasm	example

Method

The research methodology for the study comprised of describing the domain using the (a) description method of representation in the form of simple sentences (b) concept mapping method of representation. At the time of this study, the students were already taught the chapter on "*Cell Structure and Function*" by their biology teachers as per their classroom schedule. However, before the study, the same chapter was read out to the students in order to refresh them with the topic. To begin with, a subject based questionnaire was administered and the students were instructed to provide answers to the questions in a descriptive format (as is done normally during taking notes or an examination). This was followed by an introduction and familiarisation programme wherein the same students were familiarised with the concept mapping technique. The principles and the construction of concept maps were explained to the students.

Once the students were familiarised with the concept mapping technique, they performed practise session in which the students constructed a concept map on the topics of "*Food, Transport, Sports, School, Music*". These two activities ensured that the students were familiarised and had practised the concept mapping technique. This was followed by using the concept mapping method for depicting the same domain by the same students. A list of seed concepts and seed linking words were provided to the students as shown in Table 1. An important point to be noted is that in the usual concept mapping methodology only the seed concepts are provided and seed linking words are not provided. According to this method, the mapper is free to choose the linking words. However, this freedom in using the linking words from natural language has led to concept maps being

ambiguous and ineffective for science learning. In order to make maps unambiguous, precise and effective for science learning, a refined concept mapping method is proposed wherein the linking words from the set provided (as shown in Table 1) are used for mapping the domain (Kharatmal and Nagarjuna, 2006). By providing the linking words, in turn helps in recall and reflecting on prior knowledge which in itself is the factor for influencing learning which is also stated as *what the learner already knows* (Ausubel, et. al., 1978) in educational psychology. Figure 2 shows a concept map drawn by one of the students on the topic of *Cell Structure and Function.*
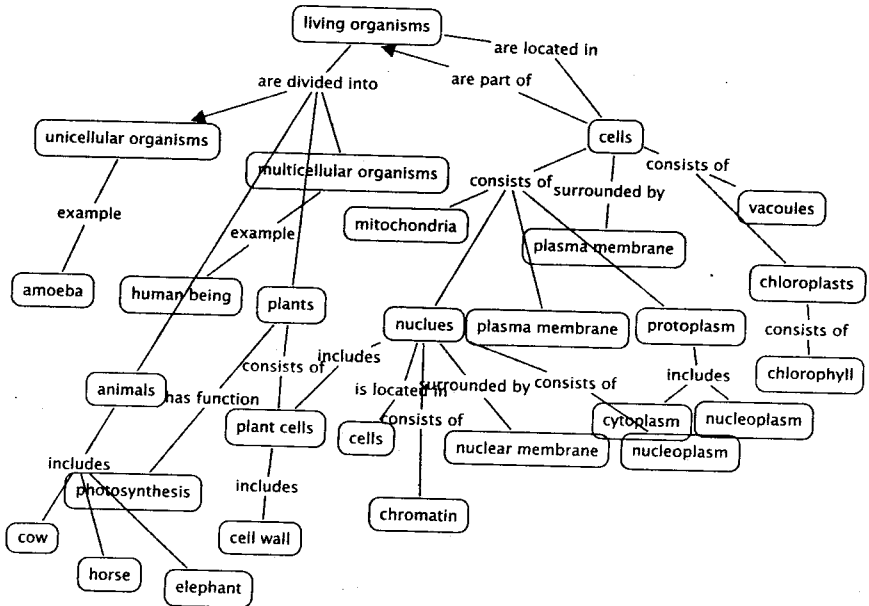

Fig. 2: *Student S1's Concept Map on Cell Structure and Function*

Analysis

Both the description and concept map forms of representations were analysed for structure of knowledge in the form of concepts and relations. An expert's map was used as a standard (Kharatmal 2006). A comparison of description method and concept map method shows that all students have an increase in the number of propositions in the concept map method by about more than two-third the number of propositions depicted using the description method. Both the methods were analysed for the content knowledge and its structure.

Content Validity

Knowledge comprises of a set of propositions in the form of concepts and linking words in both the forms of representations. Concepts and linking words both form the unit of analysis for the content validity. A score of 1 each was assigned to a non-redundant concept and 1 each for a scientifically correct proposition in both the method. The critical concepts and critical propositions are those which are essential to represent the domain. A list of critical concepts for the domain is – *living organisms, multicellular organisms, unicellular organisms, human being, amoeba, plants, photosynthesis, plant cells, cell wall, animals, cow, horse, elephant, cells, plasma membrane, vacoules, chloroplast, chlorophyll, protoplasm, mitochondria, energy-production, nucleus, nuclear membrane, chromatin, cytoplasm, nucleoplasm.*

In the description form of representation, a student S1's depiction of the critical propositions are: *"The organisms which are made up of a singe cell are called unicellular organisms". "Few of them are amoeba, paramoecium, etc". "The organisms which are made up of more than one cell are called multicellular organisms". "E.g. human beings, lion etc". "The jelly like liquid enclosed inside the cell is called protoplasm". "The protoplasm between the plasma membrane and nucleus is called cytoplasm". "Nucleus is a spherical organelle present in all cells". "It contains a network of fibrous material called chromatin network". "A few cell organelles are nuclues, mitochondrion, plastids, vacoules, etc". "An animal cell consists of plasma membrane, nucleus, protoplasm, chromatin, mitochondrion". "Some animals, have small vacoules, etc". "Animal cell does not have cell wall, plastids".*

In the concept map drawn by the same student S1, there appears 20 concepts and 29 relations or propositions. Some of the propositions depicted by student S1 using concept maps are: *"living organisms are divided into multicellular organisms"; "living organisms are divided into unicellular organisms"; "living organisms are divided into animals"; "multicellular organisms example human beings"; "unicellualr organisms example amoeba"; "cells are part of living organisms"; "cells are located in living organisms"; "cells surrounded by plasma membrane"; "cells consists of mitochondrion"; "mitochondrion has function energy production"; "plants has function photosynthesis"; "plants consists of plant cells"; "animals includes cow"; "nuclues is located in cells"; "nucleus consists of chromatin"; "nucleus surrounded by nuclear membrane"; "nucleus consists of nucleoplasm"; "cells consists of nucleus"; "cells consists of protoplasm", etc.*

The scores for ten students (the others dropped out during the time of the study) in both the forms of representations were plotted as shown in Figure 3, which shows that there has been a significant increase in the number of critical concepts and critical propositions depicted using the concept mapping method. One of the major reasons for this has been the depiction using the node-link structure which helps to anchor new concepts with the existing concepts.
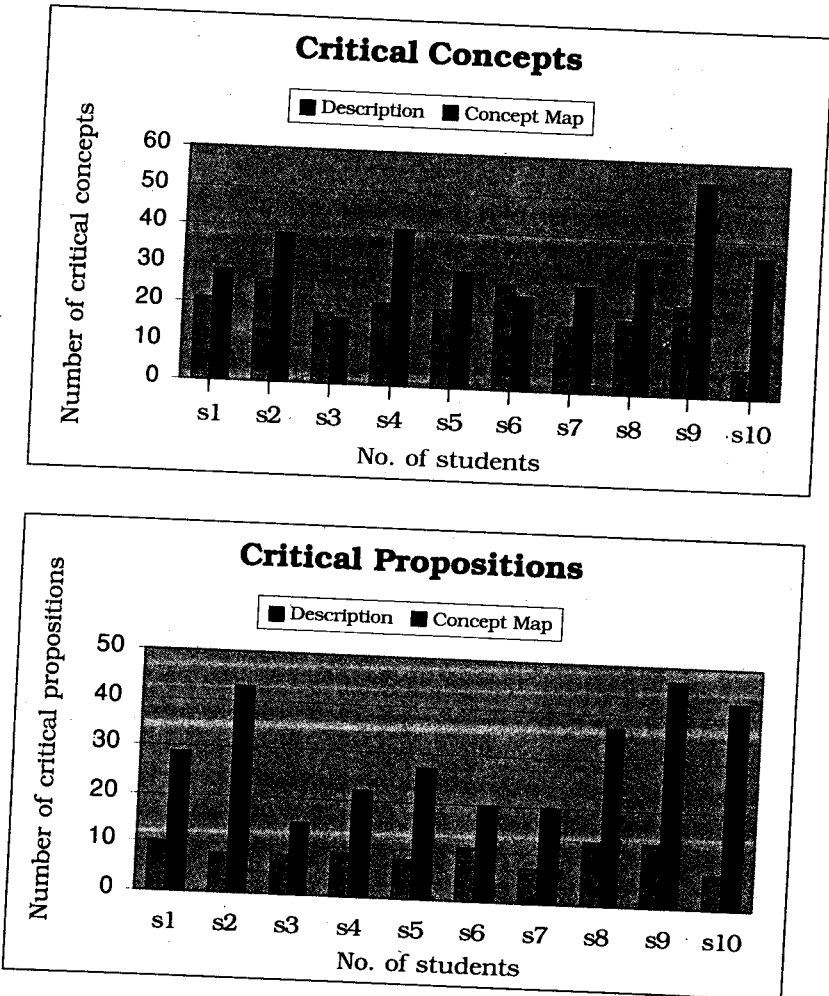
Fig. 3: Comparison of descriptive and concept map forms of representations

Structural complexity

The depiction of all the elements in a concept map are considered to suggest an overall score for the concept map. The same Student S1 has scored: 20 for non-redundant concepts; 29 for valid relations, 3 for levels of hierarchy, 5 for branches, 1 for cross link, 2 for examples. By following the scoring model the student has scored a total of 81 which is an excellent score.

Conclusion

The paper covered a short review on concept maps in science education research with an illustration of a case study in Indian school context. Two different methods of representing knowledge—description and concept maps are compared for eliciting students' knowledge structure of school biology. The case study shows that there is a significant increase in the number of concepts and valid relations when the students used the concept mapping method for representing their understanding about cell biology. This indicates that concept maps aided in recalling and networking of concepts, and have been found to be a feasibile tool in organising knowledge for meaningful learning. It shows that by using the concept mapping methodology the students used their prior knowledge to link with the new concepts thus serving as an anchoring device. The seed linking words that are provided acts as facilitator. In another two different studies in this area of research, the set of linking words was used for pointing that precision, rigor in representing the scientific knowledge can be achieved not by just the nodes (concepts) per se but due to the refinement and accurate use of linking words thus leading towards attaining expertise (Kharatmal M. and Nagarjuna G., 2008). The same set of linking words were used to show the feasibility aspect of concept mapping, wherein eventhough with the constraints applied there was found to be a significant change in the representation of accurate relations and the representation was without any loss of knowledge (Kharatmal M. and Nagarjuna G., 2009). In due course, it is planned to study the efficacy of concept mapping in teaching and assessing wherein the science courses can be taught and assessed using concept maps.

REFERENCES

AUSUBEL, D., NOVAK, J. and HANESIAN, H. 1978. Educational Psychology: A Cognitive View. Holt,Rinehart and Winston, New York.

ARNAUDIN, M.A., MINTZES, J.J., DUNN, C.S. and SHAFER, T.H. 1984. Concept mapping in college science teaching. *Journal of College Science Teaching,* 117–121.

CAREY, S. 1986. Conceptual change and science education. *American Psychologist,* 41(10), 1123–1130.

CHUNAWALA. 2006. Science Education. *Sixth Survey of Educational Research* 1993-2000. Volume I, National Council of Educational Research and Training, New Delhi.

FISHER, K., WANDERSEE, D. and MOODY, D. 2000. *Mapping Biology Knowledge.* Kluwer Academic Publishers, The Netherlands.

KHARATMAL, M. 2006. Concept map on cell structure and function. At IHMC Public Cmaps\Meena (India)\Cell Structure and Function\Cell Structure and Function. http://skat.ihmc.us/servlet/SBReadResource Servletrid=1139090479160_113084903_8482&partName=htmltext

KHARATMAL,M. and NAGARJUNA G. 2006. *A Proposal to Refine Concept Mapping for Effective Science Learning.* In Concept Maps: Theory, Methodology, Technology, Proceedings of Second International Conference on Concept Mapping, A.J. Cañas, J.D. Novak, Eds., San José, Costa Rica. http://okeanos.files.wordpress.com/2008/08/cmc2006-p151-2.pdf

KHARATMAL M. and NAGARJUNA G. 2008. *Exploring Roots of Rigor: A Proposal of a Methodology for Analyzing the Conceptual Change from a Novice to an Expert.* In Canas, A., Reiska, P., Ahlberg, M., Novak, J. (eds.) Concept Mapping: Connecting Educators, (pp.391—398). 3rd International Conference on Concept Mapping. Tallinn, Estonia & Helsinki, Finland. http://okeanos.files.wordpress.com/2008/09/exploring-roots-of-rigor.pdf

KHARATMAL M. and NAGARJUNA G. 2009. *Refined Concept Maps for Science Education: A Feasibility Study.* In Subramaniam, K., Majumdar, A. (eds.) Episteme 3: An International Conference to Review on Science, Technology and Mathematics Education, (pp.76—80). Mumbai, India. http://okeanos.files.wordpress.com/2008/12/refined-concept-maps-for-science-education-a-feasibility-study.pdf

MINTZES, J.J. 2007. Knowledge restructuring in biology: Testing a punctuated model of conceptual change. *International Journal of Science and Mathematics Education.* 5(2), pp 281-206.

MINTZES, J.J., WANDERSEE, J. and NOVAK, J. (Eds.). 1998. *Teaching Science for Understanding — A Human Consctructivist View.* USA: Academic Press.

MINTZES, J. J., WANDERSEE, J.H. and NOVAK, J.D. 1997. *Meaningful Learning in Science: The Human Constructivist Perspective.* In Gary D. Phye (Ed.), Handbook of Academic Learning: Construction of Knowledge (pp. 405-47). USA: Academic Press.

NCERT (2004): *Science and Technology—Textbook for Class VIII*, National Council of Educational Research and Training, New Delhi.

NCERT (2005): *National Curriculum Framework 2005*. National Council of Educational Research and Training, New Delhi.

NOVAK, J.D. and GOWIN, D.B. 1984. *Learning How to Learn*. Cambridge University Press, New York.

NOVAK, J., MINTZES, J. and WANDERSEE, J. 2000. Learning, Teaching, and Assessment: A Human Constructivist Perspective. In Mintzes, Wandersee J. and Novak J. (Eds.) *Assessing Science Understanding — A Human Constructivist View* pg 1–13. USA: Academic Press.

RUIZ-PRIMO, M. and SHAVELSON, R. 1996. Problems and Issues in the Use of Concept Maps in Science Assessment. In *Journal of Research in Science Teaching*, 33(6), pp. 569–600.

WALLACE, J.D. and MINTZES, J.J. 1990. The concept map as a research tool: Exploring conceptual change in biology. *Journal of Research in Science Teaching*, 27(10), 1033–1052.